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# THE GEOLOGY, PETROLOGY AND PHYSIOGRAPHY OF THE OMEO DISTRICT, NORTH-EASTERN VICTORIA

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## Abstract

A reconnaissance survey of an area in the Omeo-Glen Wills-Benambra district has been carried out.

Physiographically, this area forms part of a group of uplifted and tilted fault blocks of probably late Pliocene or Pleistocene age, on which remnants of a pre-Miocene peneplain are preserved.

The bed-rock of the area consists of schists and gneisses, forming part of the metamorphic belt of north-eastern Victoria. The former are, at least in part, the metamorphosed equivalents of the Upper Ordovician sediments outcropping on the flanks of the belt, while the latter are closely related to massive granites and granodiorites of Lower Devonian (?) age. A gradual increase in the metamorphic grade of the schists as the major gneissic intrusions are approached is traced by the incoming of biotite, cordierite, poikiloblastic muscovite, sillimanite, etc., and the gneisses are classified according to the relative importance of contamination, recrystallization and mechanical deformation in their formation. The tourmaline-rich muscovite granite of Mt. Wills and numerous aplites, pegmatites, etc., may represent the last phases of this period of igneous activity.

Younger sediments of probably Middle Devonian age are represented by shales, sandstones and conglomerates of Mt. Tambo, which overlie the schists and gneisses with a marked angular unconformity, and by the shales, sandstones, conglomerates and limestones of the Wombat Creek and Limestone Creek formations.

The red granite in the vicinity of the Blue Duck Hotel, and the syenites and granite porphyries of the eastern portion of the area are referred to a second period of igneous activity, probably of late Upper Devonian age, since they intrude certain of the Middle Devonian sediments. They are associated with abundant hypabyssal and extrusive rocks of composition comparable to the plutonic types and including some highly alkaline types. A group of more basic rocks, including diorites, lamprophyres, dolerites, etc., which are restricted in amount but very widespread in occurrence, are also tentatively correlated with this period of igneous activity, since many of them are characterized by the presence of significant amounts of albite.

The only post-Palaeozoic rocks in the area are the flows of Older Basalt in the Bogong High Plains and in the Mt. Hotham-Dargo High Plains area, and the more restricted occurrence of Newer Basalt at Frazer's Tableland, north of Benambra township, the two groups being readily distinguished by petrological and physiographic characteristics. Richly fossiliferous leaf beds and a thin seam of brown coal are associated with the former at a locality south of Mt. Jim. Nepheline phonolites near Omeo are also tentatively correlated with one of these Tertiary periods of igneous activity.

Finally, an attempt at listing and classifying the known mineral resources of the area is made.

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## Introduction

The area to be discussed in this paper is a roughly triangular block of country in the upper portion of the Mitta Mitta catchment, extending from near Omeo in the south to Mt. Bogong in the north-west and Leinster Station in the north-east. Of the total area of approximately 600 square miles, the east and south-central portions have been studied in greatest detail, but the scale of the structural and petrological units in this part of the State is such that their essential relationships are only revealed by the consideration of relatively large areas. Also in considering the physiography it is necessary to include the headwater regions of the Tambo and Wentworth Rivers in the south, Limestone Creek in the east, and the Kiewa River in the north-west.

For field mapping Parish Plans, where available, were used as base maps, supplemented by aerial photographs of the country about Omeo supplied by the Forestry Commission, and a detailed drainage map of the Bogong High Plains compiled by the State Electricity Commission. The author is also indebted to the Royal Australian Air Force for permission to accompany one of its bushfire patrols on a routine flight over the area. Pace and compass surveys were relied upon for mapping geological and topographical details, heights being calculated from aneroid readings.

## Previous Work

Of the very large number of previous references to this area, only the most important can be listed at this stage, and a number of others will be discussed in the relevant sections of the text. Of the remainder, which are listed in the bibliography, but to which no individual references have been made, the majority are notes concerned essentially with the economic and engineering details of one or other of the numerous mines formerly active in this area, and a few are merely recapitulations of earlier work.

The foremost contributions to our knowledge of the district, both in point of time and of importance, are the papers of A. W. Howitt (1876, etc.) who was the first to publish detailed descriptions of the plutonic and metamorphic rocks of the area, recognizing transitions from the mica schists of the metamorphic belt to the unaltered Ordovician sediments on either flank, and setting up criteria for the distinction between metamorphic rocks of igneous and sedimentary origin.

At about the same time, J. Stirling (1882, etc.) recognized the Bogong High Plains as the dissected remnants of an uplifted peneplain, an interpretation which has been fully upheld by later studies. Other workers who added to the knowledge of the area towards the turn of the century include W. H. Ferguson, O. A. L. Whitelaw, R. A. F. Murray, E. Lidgey, H. S. Whitelaw and E. J. Dunn, whose various papers will be referred to again later.

In more recent years, a series of more specialized studies has also been carried out in the area. These include detailed petrological accounts of the nepheline phonolites of Omeo (Skeats 1912), of certain metamorphic and igneous rocks (Tattam 1929), and of the syenites of Mt. Leinster (Broadhurst and Campbell 1932). Similarly, a number of the major physiographic features of the district have been re-examined in recent years, the studies of Kenny (1937d) and Thomas (1937), on Lake Omeo, and of Hills (1938) on Frazer's Tableland being of special interest.

In addition to papers dealing with the area itself, a number of studies in adjacent or similar areas will also be referred to for purposes of comparison and possible correlation. The most important of these are N.E. Benambra (Edwards and Easton 1937), Bindi (Gaskin 1942), and portions of the metamorphic complexes in N.S.W. (Joplin 1942, etc.), the first of these, based on the detailed mapping of a large area by J. G. Easton, being especially instructive.

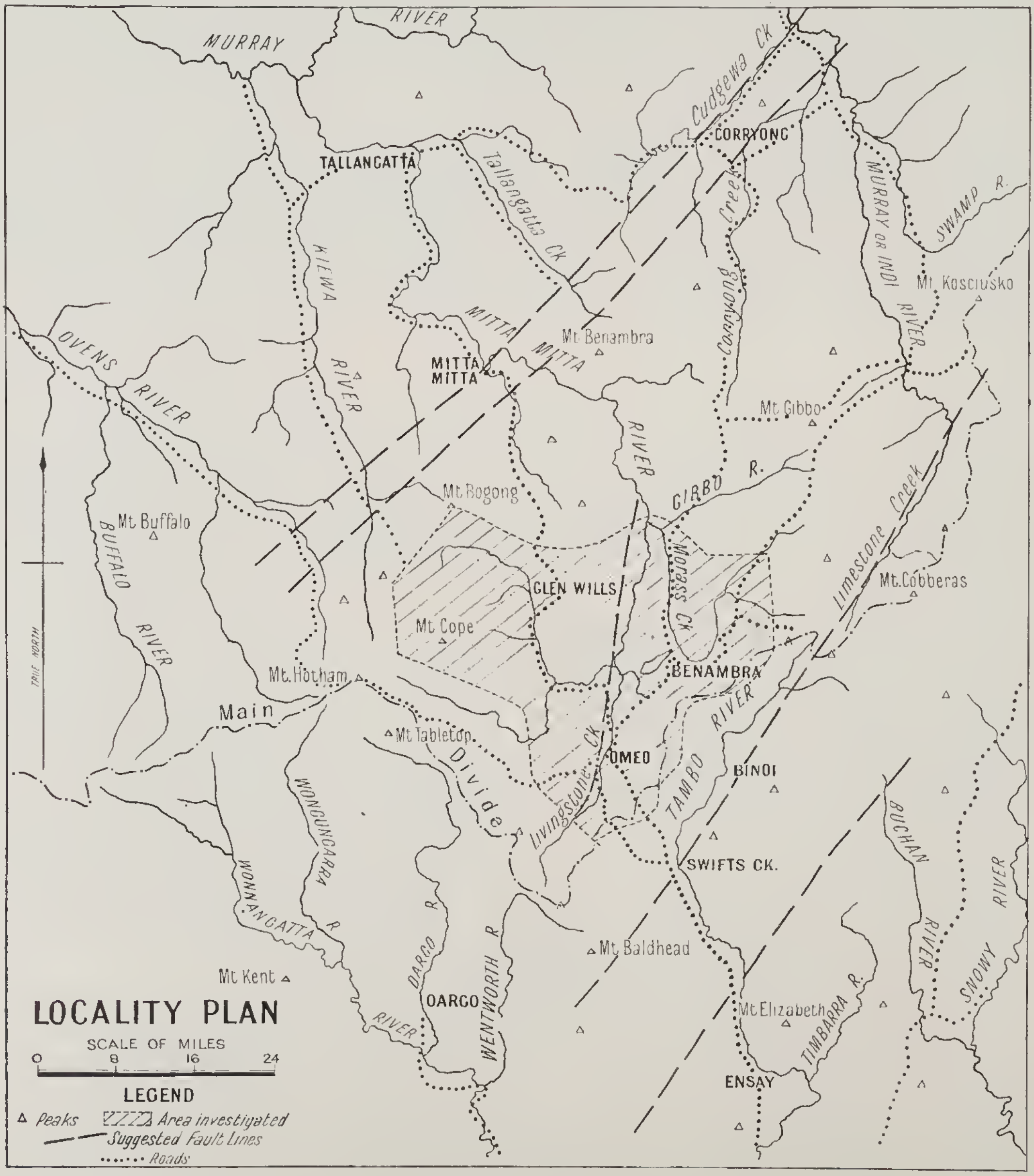


Fig. 1.—Locality Plan.

## Physiography

### DRAINAGE SYSTEMS

Most of the area falls within the drainage basin of the Mitta Mitta or Big River. This river rises in relatively gentle gullies west of Mt. Nelse at about 5500 feet, first flowing northwards. Its valley then becomes deeper and steeper and it turns to the south-east and flows in a valley with a depth of from 2000 to 3000 feet which separates Mt. Bogong and Mt. Wills from the Bogong High Plains proper. Near the confluence with Glen Wills Creek the valley cross-section becomes more open and river gravels occur 50 feet above the level of the stream. From about two miles south of this confluence the valley is again gorge-like. Valley-in-valley structure is obvious, remnants of the old valley being found at progressively higher levels downstream to Hinnomunjie Bridge. Here the river abruptly emerges on to an alluvial flat about half a mile wide and two miles long, at an altitude of about 1800 feet.

The chief tributaries in this region, Middle Creek and the Bundarra, Cobungra and Victoria Rivers, which rise in the High Plains and flow generally westward, show similar features: that is, a gentle headwater region, passing rapidly into a deeper and steeper portion which ultimately opens into small alluvial flats, as at Shannon Vale and Cobungra Station. Rejuvenation, with its resultant valley-in-valley structure, has progressed up these valleys for distances depending upon the size of the particular stream and the amount of rejuvenation undergone by the Big River at its confluence with the stream.

In the country about Hinnomunjie Bridge the Big River swings in a large bend from a general southerly to a general northerly course, the centre of this bend being the Knocker, a mountain about five miles east of Glen Wills. Similar changes of direction occur in two of its lower tributaries, the Gibbo River and Morass Creek, and to a lesser extent in the Cobungra and Bundarra Rivers. North of Hinnomunjie Bridge the valley gradually deepens and becomes gorge-like, valley-in-valley structure again being prominent. The difference in level of the old and present valleys is from 800 to 1000 feet in the vicinity of the confluences of Wombat Creek and the Gibbo River, and to the north may be even greater. All traces of the old valley are, however, lost some distance before the river reaches Mitta Mitta township, where it emerges on to another set of alluvial flats at an altitude of about 800 feet. These flats persist for the remainder of its course.

Livingstone Creek rises near Mt. Delusion at the tip of the great southerly bend which the Main Divide describes in this region. To the north of the junction of New Rush Creek, some twelve miles south of Omeo, its course is characterized by alternating river flats and small gorges up to 200 feet in depth, good examples of such gorges occurring near the Reedy Creek confluence and just downstream from Wilson's Creek. The river flats are frequently associated with deposits of old coarse gravels at levels of up to 150 feet above the present creek bed, as at Hinnomunjie Swamp, five miles north of Omeo, and at Dry Gully. A striking feature of the valley of Livingstone Creek is its pronounced asymmetry, shown by steeper and higher slopes on the west than on the east and by the more pronounced valley-in-valley structures in the western tributaries such as Dry Gully and Jim and Jack Creek, as compared with eastern tributaries such as Wilson's Creek and Day's Creek. This asymmetry can be traced some distance down the valley of the Mitta Mitta River beyond Hinnomunjie Bridge, but north of Eight

Mile Creek the effect is masked by the general deepening of the valley already referred to.

Morass Creek enters the area from the east, flowing around the north and west slopes of McFarlane's Lookout and describing a wide arc around the southern slopes of Mt. Brothers before joining the Mitta Mitta River by way of the Gibbo River. Locally it has caused alluvial flats north of McFarlane's Lookout and north-east of Mt. Leinster, ascribed by Broadhurst and Campbell (1932) to the effect of hard bars of syenite. Close to Benambra, at an altitude of about 2400 feet, the stream meanders over very much larger alluvial flats up to two miles wide, which Hills (1938) has shown to be caused by the damming of the stream by the Newer Basalt of Uplands, about six miles north of Benambra. Beyond that point the stream has been rejuvenated similarly to the Mitta Mitta and has cut a gorge comparable in depth with that of the latter.

North-east of Mt. Brothers a low saddle, only about 400 feet above the present valley of the stream, separates it from the headwaters of Deep Creek, the valley of which may have been the former course of Morass Creek. If so, the diversion around the southern end of Mt. Brothers is comparatively recent, but the reason for it has not been discovered.

Wombat Creek shows nothing of special interest in its upper course, flowing in a uniformly steep but gradually deepening valley down to a point almost opposite Limestone Gap, sometimes referred to as Toak's Gap. From there it turns abruptly south-east to join the Mitta Mitta at almost the same point as the Gibbo River. From a study of the Newer Basalt outliers preserved on the upper slopes of the present river valleys, Kenny (1937a) deduced that the drainage in this part of the valley has been reversed. Before rejuvenation the old course of the Mitta Mitta followed the lower part of the present Wombat Creek valley, crossed Limestone Gap and rejoined its present valley about eight miles north of the present Wombat Creek confluence. The reason for the diversion is not known, but the change would appear to date from the time of rejuvenation, i.e., probably Pleistocene or late Pliocene.

The north-western portion of the area is drained by the East Kiewa River, whose main headwaters are the two streams known as the Rocky Valley branch and the Pretty Valley branch which join at Bogong township. They have similar relatively simple valley forms, rising on the Bogong High Plains as very gentle gullies which open out on to restricted alluvial flats at Rocky Valley and Pretty Valley proper, at about an altitude of 5300 feet. These flats are drained by very steep gorge-like valleys which in six or seven miles drop to about 2100 feet at Bogong township. From here the valley of the East Kiewa River is somewhat more open. Near Tawonga, at about 1100 feet, alluvial flats appear and persist for the remainder of the course, as in the valley of the Mitta Mitta.

The Tambo and Wentworth Rivers drain the southern slopes of the Main Divide in the south-central and south-east parts of the area. On the whole they show less anomalous features than the north-flowing streams. Minor examples of probable river capture are provided by the headwaters of the Wentworth at Jirnkee Gap, and by Scrubby Creek, a tributary of the Tambo south-east of Mt. Sisters. In each case the streams show a sudden change in direction from north to south and low saddles across the Main Divide suggest their former courses. In the first example the saddle is still at a distinctly lower elevation than the headwaters of the stream so that a water race to Swift's Creek tapping the Wentworth River five miles below its source was brought over the Divide at the saddle.

A feature of the Tambo River, regarded as significant by Griffith Taylor (1911), is the distinct asymmetry of its drainage basin, through its receiving no major tributaries from the west.

The Main Divide has marked asymmetry, the headwaters of the south-flowing streams invariably being steeper than those of the north-flowing ones. This is clearly visible at Tongio Gap and Cassilis Gap but is a general condition as far east as Marengo and as far west as Mt. Phipps. It has been attributed to differences in the mean annual rainfall by Stirling (1882) and later workers, but other causes will be invoked in a later section of this work.

### Mountain Peaks and Ranges

Many previous workers have pointed out that the highest mountains of the area are not situated on the Main Divide but at distances up to twenty miles to the north. The Divide itself here forms a large southerly bend extending approximately from Mt. Leinster in the east to Mt. Hotham in the west. It contains a number of low saddles such as Tongio Gap, 2450 ft., and Cassilis Gap, 2500 ft., through which pass roads leading south from Omeo.

In the western half of the area a nucleus of high country is provided by the Bogong High Plains of average elevation 5300 ft. from which rise several peaks attaining heights a little over 6000 ft. These include Mt. Hotham, Mt. Cope, Mt. Fainter, Mt. McKay, Mt. Nelse and Mt. Jim, of which only Mt. Hotham is situated on the Divide. To the north of this group, and separated from it by the deep valley of the Big River, lies the unbroken range connecting Mt. Bogong (6500 ft.) with Mt. Wills (5750 ft.). Further north again, however, in the area drained by Snowy and Little Snowy Creeks, no peaks exceed 4200 ft.

In the central part of the area a progressive decrease in the level of the major peaks is apparent, eastward from the Bogong High Plains, a minimum being reached at about a north-south line through Omeo. The highest points are Mt. Livingstone (4000 ft.), Mt. Delusion (4500 ft.), Mt. Baldhead (4600 ft.) and the Knocker (4950 ft.). It is in this region that the most pronounced saddles of the Main Divide occur.

East of the north-south line through Omeo the elevation of the major peaks increases but the nature of the relief undergoes a gradual change. Isolated peaks rather than ranges and plateaus are the rule, and differential erosion has played a much more important role in determining the present topography. The main peaks are Mt. Brothers (4650 ft.), composed of syenite, Mt. Sisters (4200 ft.), composed of granite porphyry, Mt. Tambo (4850 ft.), of conglomerate, and Mt. Leinster (4750 ft.), of syenite. The last three are situated on the Main Divide. The continuation of the Mt. Bogong-Mt. Wills ridge is also strongly represented on this side of the Mitta Mitta valley and includes a group of rugged peaks and ridges culminating in Mt. Gibbo (5700 ft.).

### Relations to Adjacent Areas

Considering the area as a whole and in relation to adjacent areas, the most striking features are the close accordance of the summit levels of the various groups of peaks within it and its sharp demarcation from adjoining physiographic units. The summit levels show a gradual decrease to the south of the order of 2000 feet in fifty miles, or about 1 in 120. This is brought out by a high-point profile drawn through the area in a N.N.W.-S.S.E. direction, in which all the main peaks are shown as projected on a single section line. The sharp discontinuity just north of Mt. Bogong and the similar, but rather smaller, drop south of Mt. Baldhead are clearly revealed. The discordance of points corresponding to Mt. Buffalo and to the Cobberas is very obvious and indicates that the physiographic unit under consideration does not extend beyond the Ovens valley to the west nor Marengo to the east. The general accordance of the points representing the base of the Older Basalt flows, in a line parallel to and from 400 to 800 feet below that of the summit levels also indicates that this alignment is not accidental, and suggests that the area had already been dissected to a moderate depth in pre-Older Basaltic times.

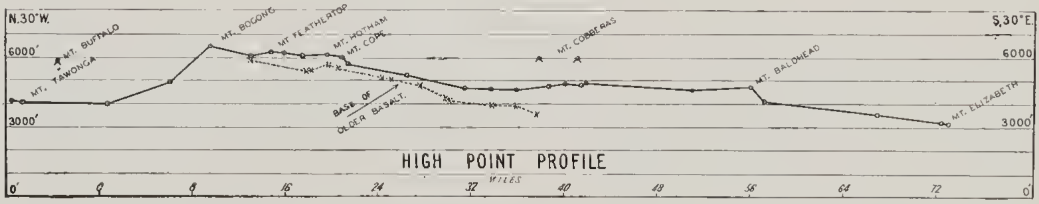


Fig. 2.—High Point Profile.

## Previous Interpretations

The most important previous interpretation of the physiography is that of Griffith Taylor (1911) in which a series of major river captures was postulated to account for the present-day topography and drainage. The Big River, Gibbo River, Morass Creek, Cobungra and Victoria Rivers were thought by him to have flowed originally southwards into the Tambo River by way of what are now the low saddles in the present Main Divide, and to have been captured by the headwaters of a north-flowing stream which headed back through the then existing divide, of which the Mt. Bogong-Mt. Wills and Mt. Gibbo-Mt. Pinnibar ranges are the present-day remnants. This theory is supported by the existence of the low saddles, by the present asymmetry of the Tambo drainage system, and by the pronounced elbows and boat-hook bends in the courses of the various streams concerned, giving rise to so-called "crossed forks" at the supposed points of capture.

The present work tends to confirm that such major river captures have taken place but, since steepening of the valleys below the points of capture is no longer in evidence, these changes must be referred to an earlier cycle of erosion. There is, however, strong evidence suggesting that the high Mt. Bogong-Mt. Gibbo group of mountains owe their elevation to comparatively recent earth movements, so that the present river system is antecedent to them. The formation of the Mitta Mitta gorge can thereby be accounted for without assuming the breaching of an old divide.

## Fault Lines

The existence of two physiographically unlike regions divided by a line trending N.E.-S.W. through Tawonga was indicated by Tattam (1929). North of the line the major rivers, the Kiewa and Mitta Mitta, flow in wide open valleys over alluvial flats up to four miles in width, separated by ranges rising abruptly from the flats but seldom exceeding a height of 4000 ft. To the south the valleys are steeper, often gorge-like, and the main peaks may exceed 6000 ft. Easton (1937) suggested that this marked discontinuity could be accounted for by a major fault running through Simon's Gap near Tawonga, up the valley of Mountain Creek, crossing the Mitta Mitta near Granite Flat and continuing down the valley of Cudgewa Creek to the New South Wales border. This has been termed the Tawonga or Mountain Creek fault.

Considering the high-point profile from this point of view, it appears that the area between Mt. Bogong and Mt. Baldhead represents a block or group of blocks uplifted approximately 2500 ft. relative to the adjoining northern area, and tilted to the south at a low angle. However, the possibility of this throw being distributed over two or more parallel or sub-parallel zones of movement cannot be neglected, and is suggested by the alignment of creeks and saddles in N.E. Benambra along two main lines, represented by Cudgewa Creek and the lower portion of Corryong Creek respectively.

The south-eastern boundary of the tilt block is indicated on the high-point profile by a break just south of Mt. Baldhead, although the displacement of the summit levels is only of the order of 500 ft. However, a line drawn through this point, parallel to the strike of the Mountain Creek Fault, again coincides with a remarkable alignment of streams and low saddles, such as would be expected along the line of weakness marking the position of a major fault. The upper portion of the Tambo River, the valley of Limestone Creek and the north-easterly-flowing portion of the Indi River, north-east of the Pilot, all follow this line.

A strong scarp, 400 ft. to 500 ft. high, running approximately N.N.E.-S.S.W. and facing south-east, can also be recognized in the Tambo valley between Ensay and Swift's Creek and may form part of this or a related fault line.

The most striking effect of these faults on the drainage system has been the rejuvenation of the streams draining the upthrown blocks. The Ovens, Kiewa, Mitta Mitta and Indi Rivers all flow in deep gorge-like valleys for part of their course, emerging more or less abruptly on to gentler valleys and alluvial flats on the downthrown blocks. In the case of the Ovens and Diamantina or West Kiewa River, rejuvenation is complete up to the headwater region, but the Mitta Mitta and East Kiewa Rivers still show well-defined knick-points.

The former, carrying the larger volume of water, and hence possessing superior powers of erosion, has cut back its gorge to the vicinity of Eight Mile Creek, a distance of approximately 25 miles from the line of the Mountain Creek Fault, with a corresponding development of knick-points in its major tributaries, such as Morass Creek, Wombat Creek and the Gibbo River. In the East Kiewa River, on the other hand, rejuvenation has only proceeded for a distance of ten or twelve miles and the knick-points are represented by the outlets of the very gentle locally swampy basins of Rocky Valley and Pretty Valley, in which extensive alluvial flats have been deposited by the creeks.

These alluvia have been attributed by Kenny (1937c) to the blocking of the old outlets of these basins by the basalts of Mt. Jim and Basalt Hill respectively. However, in view of the great age of these flows and their probable much greater original extent, it is unlikely that any portion of the pre-Older Basalt drainage system now survives as such, and it is most improbable that such a relatively minor modification should have been preserved from Oligocene or Lower Miocene times.

An alternative explanation in terms of the tilt of the upthrown block appears more probable. This tilt has resulted in a reduction of the grade of the north-flowing streams throughout the affected area, which should thus tend to develop alluvial flats, while the grade of the south-flowing streams has been increased and their powers of erosion augmented. This difference would account not only for the presence of alluvial flats in Rocky Valley and Pretty Valley and their absence at corresponding points in the headwater regions of Middle Creek and the Bundarra and Cobungra Rivers, but also for analogous features elsewhere in the area. Thus it explains the previously mentioned asymmetry of the Main Divide with very much steeper southern than northern slopes, and may also account for a number of river captures in which originally north-flowing streams have been diverted to the south. The Big River near Mt. Arthur, the Wentworth at the Jirnkee Gap and possibly also Scrubby Creek south-east of Mt. Sisters are examples of this type of capture.

The Livingstone Creek Fault has left a major physiographic feature which can be traced for almost twenty miles along the steep west banks of the Livingstone Creek and Mitta Mitta valleys, between Jim and Jack Creek in the south and Eight Mile Creek in the north. The vertical displacement on this fault is of the order of 600 ft. to 800 ft., and from the excellent state of preservation of the scarp its age is regarded as being no greater than that of the youngest major Central Victorian and South Gippsland faults, possibly post-Pliocene.

This fault has again given rise to marked rejuvenation and valley-in-valley formation of the streams draining the upthrown (western) block, especially the Big River and its major tributaries. The western tributaries of Livingstone Creek have also been affected, Dry Creek, Mountain Creek and Jim and Jack Creek providing the best examples.

The effect on the Mitta Mitta River below Hinnomunjie Bridge and on Livingstone Creek itself, both of which might be described as fault-angle streams, has been more complex. Wherever the original course of the streams traversed portions of the present upthrown block, they have been diverted to the east, leaving old river gravels perched between 600 ft. and 800 ft. above their present valleys, as on the old Glen Wills-Benambra road over the Knocker and at Mt. Mesley, west of Omeo township. Upstream of such points, the streams were temporarily dammed back, and heavy, rudely stratified gravels, with interbedded sands and clays, were deposited, probably under lacustrine conditions. These attain a thickness of up to 100 ft., as at the mouth of Dry Creek and on the Omeo-Hinnomunjie Bridge road, west of Hinnomunjie Swamp, where they have been tested by bores (Stirling 1887c). In every case, the creek has completed the downcutting of its valley to the base of these gravels, so that its present level is everywhere below that of its pre-fault ancestor, the difference increasing northwards and possibly reaching 200 ft. near the mouth of Reedy Creek, about eight miles north of Omeo.

The Reedy Creek-Morass Creek Line is another probable line of weakness. East of Omeo township the spurs rise, at first gently but finally much more steeply, to the Main Divide, which gradually decreases in altitude from Mt. Sisters to the Tongio Gap. In the northern part of this area the headwaters of Reedy Creek flow practically parallel to the Divide, which rises abruptly. North of the Benambra lowlands the line of this abrupt rise is taken up again by the steep west face of the Mt. Brothers massif, along the foot of which Morass Creek flows. This line coincides closely with the western boundary of that physiographic region in which differential erosion has exercised a controlling influence upon topography, suggesting that uplift in this portion was initiated rather earlier than elsewhere in the area. The Reedy Creek-Morass Creek Line may thus represent an older line of weakness than those discussed above. The evidence for this line being a fault is, however, not conclusive.

The important role ascribed to faulting in this area is in good accord with observations in the Kosciusko district, about 45 miles to the north-east, where Browne, Dulhunty and Maze (1944) have described a series of tilt blocks with comparable displacements and have identified valley-in-valley structures, fault-angle streams, etc.

## EVOLUTION OF PRESENT LAND SURFACE

A number of stages in the evolution of the present-day topography can be reconstructed from a study of the various remnants of older erosion surfaces preserved in the area. The oldest land surface of which remnants may still be recognized is represented by the concordant summit levels of the highest peaks, as shown on the high-point profile. This had already been maturely dissected in Older Basaltic times and must therefore be identified with the epi-Cretaceous peneplain postulated by a number of workers in other parts of the State (Hills, 1934, 1940, etc.).

At the time of extrusion of the Older Basalts, this had been maturely dissected to give local relief of the order of 1000 ft., the value increasing generally in a southward direction, as indicated by the maximum difference in level between the remnants of the epi-Cretaceous peneplain and the base of the Older Basalt flows. The widespread occurrence of sub-Older Basaltic gravels, clays and leaf beds suggests the existence of a mature river system at this stage, but the extent to which the Older Basalt flows modified this drainage cannot be ascertained.

The first movements leading to the present elevation of the area cannot be dated accurately, but must pre-date the Newer Basalts by some considerable time. They appear to have consisted of a regional upwarp, possibly accompanied by local faulting, as on the Reedy Creek-Morass Creek line, and the reversal in the direction of flow of the Big River, Gibbo River, and other major streams may date from this time.

By Newer Basaltic times (Late Pliocene-Pleistocene?), the present drainage system had been developed with most of its major features. In the western portion of the area, relief was still very moderate, especially in the vicinity of the Bogong and Dargo High Plains. In the eastern portion, on the other hand, relief of the order of 1500 ft. was typical, and greater differences existed locally, as at Mt. Brothers, Mt. Tambo and Mt. Leinster.

As shown by the configuration of the old valleys of rejuvenated streams, and by the sub-Newer Basaltic leads corresponding to the old Mitta Mitta and Morass Creek valleys, the rivers of this time flowed in wide, gentle valleys, from the edges of which the major peaks and ranges rose relatively steeply. The general appearance of the area would thus have been closely comparable to that still predominating on the adjacent northern block, e.g., at Mitta Mitta and Tawonga townships.

The effect of the Newer Basalt which flooded the Mitta Mitta and Morass Creek valleys from Uplands to the vicinity of Limestone Gap, a distance of approximately ten miles, was purely local. Morass Creek was dammed back temporarily and the deposition of alluvial flats took place for about eight miles upstream of the barrier at Uplands, the maximum width of the deposits being about two miles.

The most recent movements in the area are the previously described faults along Mountain Creek, Livingstone Creek and the upper Tambo River, none of which have caused any major changes in the courses of the larger streams. The age of these faults relative to the Newer Basalt cannot be determined, since the time required for the cutting back of the Mitta Mitta gorge from the line of the Mountain

Creek fault to the lowest point reached by the basalt is not known. The basalt may thus have been extruded after the faulting had occurred, but before the rejuvenation had extended to that portion of the stream which the basalt now covers.

### Local Base Levels

The present stream systems appear to be re-establishing equilibrium at levels between 800 ft. and 1200 ft., as seen in the Mitta Mitta River at Mitta Mitta township, in the Kiewa River at Tawonga, etc. Local base levels, due to geological controls, play an important part in the development of some of the major streams. Thus Morass Creek, which has deposited alluvial flats behind hard bars of syenite at Mt. Leinster and McFarlane's Lookout, has been described as a superimposed stream by Broadhurst and Campbell. The Tambo River at Doctor's Flat and at Ensay shows the same features, the metamorphic aureole around the granitic mass of Mt. Hopeful acting as a hard bar in this case.

### Glaciation

No traces of Recent or Late Tertiary glaciation were found anywhere in the area, and all the evidence cited by previous authors was found to be readily explained by other means.

Browne, Dulhunty and Maze (1944) have shown that evidence of glaciation in the Kosciusko area is restricted to levels above about 5000 ft. For this reason, references by Lendenfeld (1886) to a terminal moraine in Mountain Creek at 2000 ft., and by Stirling to glacial pavements and former moraine-dammed lakes in the Livingstone Creek valley at about the same altitude, may be disregarded. Moreover, the formation of these lakes has already been shown to be related to movements on the Livingstone Fault.

The same authors also claim evidence of glaciation on Mt. Bogong at levels above 5500 ft., including striated pavements and glacial erratics, the latter being described as facetted boulders of hornblende diorite, originally derived from the High Plains to the south. During the present investigation, abundant outcrops of these diorites were found throughout the highest portions of the Mt. Bogong massif, and the presence of the so-called facetted boulders is thought to be due to their well-developed tendency to break into angular blocks parallel to closely spaced joint planes. In addition, the northern portion of the Bogong High Plains, immediately opposite Mt. Bogong, was found to be singularly free from these diorite dykes, no outcrops being found nearer than the East Kiewa valley, and then only at elevations of 4500 ft. or less. The striated pavements proved equally inconclusive, no occurrence being seen which could not be satisfactorily explained by the action of water- or wind-borne debris.

## Geology

### Schists

Most of the area falls within the metamorphic belt of north-eastern Victoria. The sedimentary members of this metamorphic complex, referred to as the Omeo Series by Howitt (1887), are regarded as the altered equivalents of mainly the Upper Ordovician slates and sandstones of the lower part of Wombat Creek and elsewhere, recorded by Ferguson (1899) as containing *Climacograptus bicornis* and *Dicellograptus elegans*. The possibility of at least some of these rocks being the equivalents of Middle Ordovician or even older sediments is, however, indicated by the occurrence of Middle Ordovician graptolites on the lower Gibbo River, at a locality some miles east of the above locality. (Dr. D. E. Thomas, personal communication.)

Throughout the area arenaceous and argillaceous beds alternate with great regularity, the thickness of the individual beds ranging from a few inches to a few feet. No calcareous beds nor conglomerates were encountered and no trace of any interbedded volcanic or pyroclastic rocks were seen. In the absence of marker beds no estimate of the total thickness of the beds involved can be given.

## STRUCTURES

The belt as a whole is markedly asymmetric in this area, the zones of medium and low grade schists being very much wider on the eastern flank than on the western. Thus the transition from almost unaltered sediments to strongly foliated, medium-grained two-mica schists in the middle and upper portions of Wombat Creek occupies five to six miles, while corresponding types at Mt. Hotham can be found within one or two miles of each other. Since the dominant dips, at least in the vicinity of Omeo, are to the east, these observations conflict with those of Joplin on the Cooma complex (1943), in which she found the metamorphic zones to be widest on the flank away from the dominant dip of the beds.

In the central part of the area, strikes of from 330° to north-south and dips of 60° to 80° are typical, easterly dips predominating somewhat, as shown by the almost continuous section along the lower part of Reedy Creek. Major fold axes are spaced at distances from five to ten chains apart, but minor folds of amplitudes from a few inches to about half a chain are not uncommon. The crests of the folds are typically sharp but not angular. The pitch is usually small, although a number of minor folds in the lower part of Dry Creek show south-easterly pitching of from 30° to 90°. Where overfolding has occurred the overfolded limb may be inclined as much as 20° from the vertical, but even then the folds are rarely isoclinal. Such structures are revealed in Reedy Creek, the overturning being to the west.

As the centre of the metamorphic belt is approached in the vicinity of the Bogong High Plains, the dips tend to be lower, and the beds are sub-horizontal over considerable areas. Insufficient time was available to map these structures in detail, but work now being carried out by officers of the Geological Survey may ultimately reveal the significance of this difference, which tends to support Tattam's suggestion that the metamorphic belt as a whole represents an anticlinal structure.

Further north again, on the southern slopes of Mt. Bogong itself, the dips are uniformly N.E. at 60° to 70° over an area of several square miles, suggesting isoclinal overfolding. Similar relationships have been described by Tattam from the adjacent Mitta Mitta and Tawonga districts, the dips there, however, being to the S.W. No reason for this reversal can be suggested, but an extension of the present work to the northern slopes of Mt. Bogong and the headwater regions of Snowy Creek would be expected to reveal other significant features.

Regional deviations of the strikes from the dominant N.W.-S.E. direction are found in three main areas. Thus irregular variations, not traceable to any definite cause, are found in the upper portions of the Knocker, east of Glen Wills, and on the eastern slopes of the Livingstone Creek valley in the vicinity of Omeo.

A more widespread deviation is noticeable in the eastern portion of the area, especially in the vicinity of Mt. Brothers and the Marengo Gap, where strikes bearing between 30° and 60° are dominant over areas of several square miles.

The transition is accompanied by the development of pitching folds and may be due, at least in part, to the intrusion of the younger plutonic masses of that district. Thus a number of minor folds south-west of Mt. Brothers can be seen to pitch almost vertically, the strike of the limbs being about 330° and 70° respectively, and that of the axial planes 110°.

Schistosity is always parallel to the bedding of the original sediments, as may be well seen in thin section 6625 (University of Melbourne collection), which contains alternating bands of contrasting composition. No foliation parallel to the axial planes of the folds is found in any of the recrystallized rocks, although slaty cleavage is strongly developed in the argillaceous sediments on either side of the metamorphic belt. The absence of this axial plane foliation is regarded as significant in assessing the relative importance of recrystallization and mechanical deformation in the metamorphism of these rocks, cf. Fairbairn (1935).

Schistosity parallel to the bedding can be developed by recrystallization alone (mimetic crystallization), but would be destroyed by intensive deformation, unless the beds were first folded isoclinally. The essentially igneous nature of the metamorphism is thus indicated, and is supported by the general parallelism of the various zones with the limits of the major gneissic intrusions within the belt, and by the presence in the inner zones of minerals characteristically developed only in the presence of volatiles and magmatic solutions. As pointed out by Tattam, it is contact metamorphism in the widest sense.

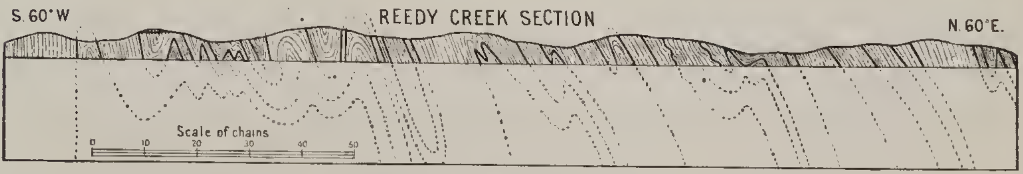


Fig. 3.—Reedy Creek Section.

Lineation as well as foliation is developed in many of the medium and high grade metamorphic rocks. Its inclination to the horizontal varies, but in the few instances where its relationships could be checked it was found to be parallel or sub-parallel to the axes of nearby minor folds, suggesting that it coincides with the *b*-direction (tectonic axis) of Sander. It may be due to minute corrugations of the schistosity planes, to the dimensional parallelism of inequidimensional grains or nodules, or to a combination of these factors (6703, 6704, 6626, etc.).

Jointing is not typically well developed, but occasionally two sets can be distinguished, as in the lower portion of Reedy Creek. There the dominant set corresponds to an (*h0l*) plane of Sander, i.e., parallel to the strike of the beds, but dipping at angles of 60° to 90° to the bedding planes. The spacing of this set varies irregularly and the joints occasionally pass into reverse faults of up to 4 ft. or 6 ft. displacement. The second set is represented by less numerous joints which, however, show a strong tendency to be concentrated in the vicinity of the fold axes. These are the *ac* joints of Sander, normal to the pitch of the folds. They are readily distinguished from the first group by their tendency to be infilled by veins of quartz up to 1 in. in width. These observations are consistent with the interpretation of the (*h0l*) joints as due to shear and the *ac* joints as due to tension (Sander 1930).

## Petrology

In a very general way, metamorphism can be regarded as increasing from north-east to south-west, as the main igneous contact of the area, extending from the Tongio Gap, south-east of Omeo, to the Big River valley, south of Mt. Bogong, is approached. The various zones are sub-parallel to this contact, but higher grade rocks surround many isolated masses of gneiss west of the main contact, as at Mt. Leinster and east of Mt. Bung Bung.

### *Low-grade Schists*

The least altered sedimentary members of the Omeo series in the area are restricted to the north-eastern portion, where they outcrop at the previously mentioned Wombat Creek locality and in the Mitta Mitta valley, downstream from Four-Mile Creek.

To the south and east, these beds grade into others, in which distinct traces of shearing and incipient recrystallization can be recognized even in the hand-specimen. Such rocks form the dominant types in the eastern portion of Frazer's Tableland, to the north of Mt. Brothers and in the immediate vicinity of Benambra township.

Argillaceous beds have typically been more altered than their arenaceous counterparts, and show a tendency towards the development of sericite flakes in good parallelism over areas up to ·5 mm. in diameter, which may be the forerunners of the spots and nodules of the higher grade schists. The individual flakes, however, remain too small to be distinguished clearly (6627).

The more arenaceous types are usually strongly inequigranular, a fine-grained matrix being frequently present even in rocks containing a high proportion of grains over ·2 mm. in diameter. The majority of the coarser grains are sub-rounded and sub-equidimensional. They may consist essentially of quartz, but more commonly other minerals are also present in significant amounts. These may include clastic felspar, tourmaline, muscovite, biotite and magnetite. The state of preservation of all these minerals varies considerably, but in some of the specimens they are so fresh as to preclude the possibility of very extensive transport (6628).

Quartz veins are frequently very abundant, but do not usually exceed ·5 mm. in width. They may be arranged sub-parallel to the bedding or to a well-marked set of joint planes, or they may appear to intersect the rock in random directions.

### *Medium-grade Schists*

With increasing grade of metamorphism, the rocks pass into the biotite zone, which covers a large proportion of the area and is especially well represented on the southern slopes of Mt. Bogong and in the headwater regions of Reedy Creek, Red Gap Creek and Wilson's Creek, all north-east of Omeo township. The incoming of the index mineral appears to be almost simultaneous in arenaceous and argillaceous beds, and, except for a progressive increase in the size of the individual flakes, no differences have been noticed between the biotites from different parts of this zone. The dark red-brown varieties are regarded as typical, and the frequent occurrence of pale brown or greenish-brown types is thought to be due to retrograde changes, being commonly associated with other evidence of decomposition or hydrothermal action (6629, 6630, etc.).

The primary constituents of most rocks in this group show no features of special interest, except for a series of specimens from the headwater region of Reedy Creek and Red Gap Creek (6631, etc.), in which finely grained graphite becomes an important constituent. In the finer-grained, more argillaceous rocks the parallelism of the reconstituted micas is usually very well developed, but in the coarser-grained, arenaceous types the alignment may be much less complete (6630, etc.). Such rocks are more closely allied to the schistose hornfelses of Tattam than to true schists.

### *Cordierite-bearing Rocks*

As the grain size of the reconstituted micas increases, the spots of incipient cordierite, which appear early in the biotite zone, tend to be more sharply defined. The incoming of this mineral, however, cannot be used to define a new zone, since it readily breaks down again to fine-grained aggregates of chlorite and white mica, which have been referred to as pinite by Tattam. These aggregates, due to retrograde changes, cannot be readily distinguished from those knots of micaceous and chlorite flakes which precede the formation of cordierite, except in a few cases, in which the crystal form or cleavage of the cordierite are preserved in the pseudomorph.

Cordierite is developed earliest and most abundantly in the more argillaceous beds, where it gives rise to subhedral crystals up to 5 mm. long, with their longest diameters, parallel to the *c*-axis, coinciding with the schistosity planes. Replacement by pinitic aggregates is usually more or less complete, but even in totally replaced crystals the external form and characteristic basal parting of the original mineral may be preserved, as in a specimen from the Knocker (6633). More commonly, however, the pinitic aggregates are elliptical, or lenticular, and the planes of schistosity of the matrix conform closely to their outlines. 'Tails' of quartz are frequently formed in the protected angles at the extremities of the nodules, and occasionally the nodules themselves may be intersected by narrow quartz veins (6633).

The pseudomorphs frequently show a layered structure, comparable to that described by Tattam in rocks from Mitta Mitta, alternate layers varying in grain-size and mineral contents. The finer-grained layers consist essentially of pinite in which the individual flakes are barely distinguishable, while the remaining ones contain various proportions of relatively large flakes of muscovite and biotite, up to ·5 mm. in diameter, scattered through a similar pinitic matrix. The arrangement of the larger flakes within the nodules may be haphazard or may be controlled by the original basal parting of the crystals (6635). Uniformly small rounded quartz granules, of average diameter ·05 mm., may also be scattered through the nodules, giving a characteristic 'sieve texture,' which is the equivalent of the original poikiloblastic texture of the cordierite.

A rather less common texture, comparable to one described by Broadhurst and Campbell from Mt. Leinster, can also be seen in the same rock (6635), from the southern slopes of Mt. Bogong. A rim of muscovite flakes around one of the nodules shows parallelism to the 001-parting of the original cordierite in its inner portion, but the flakes are curved so as to conform to the schistosity of the matrix near its outer edge. This, together with a tendency for the enclosed quartz grains of this nodule to lie on S-shaped curves, suggests that rotation of the porphyroblast took place during the final stages of its growth, i.e., para-crystalline deformation.

In the arenaceous equivalents of these cordierite-bearing rocks no significant development of new minerals, as compared to the earlier stages of the biotite zone, takes place at this stage. There are, however, a number of marked textural changes. Quartz shows obvious signs of recrystallization with the formation of outgrowths in optical continuity with the primary grains (6636, 6637), and in the more inequigranular rocks the coarser grains may show undulose extinction, while the smaller ones extinguish cleanly (6638). Tourmaline shows signs of having been introduced or reconstituted in some of these rocks, but its distribution is highly irregular, apparently depending on local concentrations of the mineralizers involved in its crystallization. Clastic felspar, if originally present, is usually completely sericitized at this stage, and may be replaced by relatively coarse-grained micaceous aggregates (6639, etc.).

Cordierite is only rarely developed in these arenaceous rocks, forming irregular poikiloblastic or interstitial grains, which are typically less pinitized than their equivalents in the argillaceous rocks (6640, 6641).

A very characteristic feature of these rocks is the development of super-individuals of quartz, as is well shown by rocks from Wilson's Creek (6642) and Mt. Bung Bung (6643). In these specimens, strongly recrystallized quartz shows dimensional orientation which gives a slightly schistose appearance to the rocks, both in thin section and in the hand specimen. However, a large number of adjacent or sub-adjacent grains will frequently extinguish simultaneously, thus revealing the presence of 'super-individuals,' which are not necessarily themselves elongated parallel to the schistosity. Similar features have been described by Sander (1930) and Fellows (1943), but their interpretation is not yet clear.

### *High-grade Schists*

On still closer approach to the main igneous masses of the metamorphic belt, evidence of recrystallization under the action of magmatic gases or solutions becomes very strong and appear to have outlasted the action of directed pressure.

Any original cordierite crystals or pinite nodules lose their sharp demarcation against the matrix and tend to enclose a higher proportion of relatively large euhedral flakes of both biotite and muscovite (6644, etc.). Tourmaline becomes very much more abundant and a second generation of white mica makes its appearance. This consists invariably of larger, strongly poikiloblastic flakes, up to 2 mm. in diameter, arranged in random crystallographic orientation, although they may show distinct elongation parallel to the schistosity of the rock as a whole. These flakes rarely show evidence of mechanical deformation. They are close to muscovite in having optic axial angles of 20° to 30°, but differ in showing slight pleochroism, pale brown to colourless, suggesting a slightly higher Mg- or Fe-content. As with cordierite, the development of these oblique micas is earlier and better in argillaceous than in arenaceous rocks. Various stages in their development can be observed in a number of specimens from scattered localities—for example, incipient growth (6645, 6646), fuller development (6647, 6648), and the extreme stage (6649).

Rocks showing these phenomena are especially well developed in the lower portion of Red Gap Creek, east of Omeo, and in the Big River valley between Mt. Bogong and Mt. Nelse.

### *Sillimanite Schists*

Sillimanite is restricted to rocks occurring very close to major igneous contacts, but its first appearance cannot be used to define a zone in the field, since its development is frequently intensely localized. It may develop either in quartz, as isolated needles or radiating aggregates, or in biotite as dense bundles of fibres.

These fibres may almost or completely replace the host biotite and may develop into thicker rods, with characteristic transverse parting. Rocks from Red Gap Creek (6650, 6651), Mt. Bogong (6652) and Mt. Wills (6653) show these phenomena. Similar observations were recorded by Tattam in schists from the northern part of the metamorphic belt.

The extremely localized nature of these changes is well shown by a rock from Mt. Bogong (6654, 6655). Here, sillimanite is replacing a rock characterized originally by the presence of poikiloblastic muscovite and cordierite. The latter occurs as irregular grains and crystals, up to 1 cm. in diameter, which enclose quartz granules, small euhedral biotite flakes, and also some of the relatively coarser muscovites. The change begins with the fibrolitization of the biotite, but ultimately involves all the other above-mentioned minerals, the final product being an aggregate of almost pure sillimanite and the change being complete within the dimensions of a thin section.

### *Felspathic Schists*

Poikiloblasts of alkali felspar occur in a number of specimens, including the last-described, but their relationships are best shown in a rock from T-spur, in the Big River valley (6656). In the hand specimen, this rock has a characteristic appearance due to the development of two generations of 'spots'. The first, due to the original poikiloblasts of cordierite, now represented by fine-grained micaceous aggregates up to 8 mm. in diameter and enclosing numerous minute quartz granules, are poorly defined and darker than the main mass of the rock. The second, consisting of irregular poikilitic alkali felspars, do not exceed 1 mm. in diameter, but are sharply defined and lighter in colour than the surrounding matrix. In the absence of chemical analyses, it is not possible to assert definitely the magmatic origin of this felspar, but the textures and field relationships of these rocks very strongly suggest such an explanation.

A rather different type of contact phenomenon characterizes the Dry Creek-Three-Mile Creek area, to the south and west of Omeo township. Here, bands and lenticles of schist which have undergone extreme recrystallization and possibly addition of igneous material, are intercalated with augen gneisses due to the mechanical deformation of originally massive igneous rocks. A typical specimen from Mountain Creek (6657) has preserved the sedimentary alternation of argillaceous and arenaceous bands with an average thickness of 2 to 5 mm. The argillaceous bands consist chiefly of sericitic aggregates, slightly bleached biotite and occasional muscovite, while the arenaceous bands are composed almost entirely of quartz and felspar. The latter apparently belongs to two distinct generations, one completely sericitized and often sub-rounded, suggesting clastic origin, the other clear, typically strongly zoned, often rich in enclosed granules of quartz. Occasionally a sharply defined sericitized core is surrounded by a clear rim, suggesting a moulding of the introduced felspar on the older clastic grains. Pyrite has also been introduced into this rock.

Similar relationships are shown by rocks from Dry Gully (6658) and Livingstone Creek (6659), the latter in addition showing again the development of 'super-individuals' of quartz elongated obliquely to the schistosity. These rocks are the equivalents, on a small scale, of the 'granular gneisses' which form one of the major rock types of the Bogong High Plains and which will be discussed in detail in a later section.

## Older Intrusives

The older intrusives of the area, comprising the gneisses of the Omeo Series and their massive plutonic equivalents, are the dominant rock types to the south-west of a line passing from the Tongio Gap, south-east of Omeo, to the Big River valley between Mt. Bogong and Mt. Nelse. Isolated stocks of the igneous rocks do occur to the north and east of the line, notably in the Mt. Leinster district, and there are a number of inliers of schist among the dominantly igneous rocks to the south and west, but the main contact is clearly defined for the greater part of its length.

Howitt (1887) mapped the southern portion of this contact as a fault junction and described it as a line, along which the schists had been let down into a magma chamber. However, even if such a movement had occurred, for which there is no direct evidence, the original fault junction would have been obliterated by the metamorphism and partial assimilation resulting from the juxtaposition of the magma and the sediments, so that the present boundary is best regarded as a normal intrusive contact.

In the area as a whole, rock types can be found to illustrate every stage of the series from massive igneous rocks to strongly gneissic types, and the latter can be further subdivided according to the relative importance of contamination, recrystallization and mechanical deformation in their development. Wherever contrasting types are directly in contact, as in Rocky Valley, Pretty Valley and in Livingstone Creek near the junction of Three-Mile Creek, the massive rocks can be seen to be the youngest members of the series, transgressing the banded structures of the gneisses, and locally giving rise to apophyses which penetrate the gneisses for a distance of a few feet, usually parallel to the foliation.

Granodiorites make up the great majority of the massive intrusions, but one occurrence of granite and one of quartz diorite are included in this group because they show similar structural and field relationships.

### GRANODIORITES

Granodiorites have been examined from Day's Creek, Livingstone Creek, Frazer's Tableland, Rocky Valley and Mt. Leinster. Heavy mineral analyses of these and other rocks described are given in Table 1 and Rosiwal analyses in Table 2.

The occurrence from Rocky Valley and Basalt Hill (6665, 6666) may be regarded as typical of this group. It is a light grey, medium-grained, even-grained rock, showing no banding or parallel arrangement of any of its constituents. Andesine, $Ab_{65}$ to $Ab_{60}$, is the dominant felspar, occurring as squat, subhedral crystals up to 2 mm. long, typically strongly zoned and frequently showing sharply defined sericitized cores surrounded by clear rims. Orthoclase occurs as larger, less numerous, irregular grains, poikilitic towards all the other minerals present. Biotite forms sub-rectangular flakes, up to 2 mm. long, occasionally with pleochroic haloes, typically deep greenish brown in colour, occasionally chloritized. Muscovite occurs as rather less abundant and less regular flakes, either independently or in close association with biotite.

Quartz forms irregular grains, up to 2 mm. in diameter, tending to be interstitial in habit and frequently enclosing small plagioclase crystals and biotite flakes or moulded on larger individuals. Epidote, magnetite and apatite are the most important minor constituents.

The least recrystallized rocks from Livingstone Creek are closely comparable to the above, except for a slightly higher content of chlorite and epidote and the presence of a few pinitic aggregates up to 1 mm. in diameter, which may represent original cordierite crystals (6663). Here, however, such rocks grade into those showing the first traces of recrystallization (6662). The quartz tends to be recrystallized with the formation of interlocking grains showing crenulated boundaries against one another, and a slight tendency towards a parallel arrangement of the biotite flakes can be detected in the hand-specimen. Rocks which have suffered a comparable amount of recrystallization also occur in the Mitta Mitta valley near the junction of Four-Mile Creek (6664), and at the head of the Bundarra River near Mt. Jim (6668).

A slightly more advanced stage of recrystallization is displayed by rocks from Mt. Nelse (6669), and from Dry Creek, west of Omeo (6670). In these specimens biotite has been affected, as well as quartz, the larger flakes being frequently distorted and the smaller ones being obviously aligned in layers which curve around the larger felspar crystals and the aggregates of recrystallized quartz. Bleaching and chloritization of the biotite are more advanced in these rocks than in the comparable massive types, and the proportion of epidote is distinctly higher.

### QUARTZ DIORITE

The only hornblende-bearing plutonic rock in the area to be correlated with the granodiorites is a quartz diorite from the lower portion of the Bundarra River valley (6672). Euhedral to subhedral andesines, $Ab_{60}$, up to 1 mm. in diameter, show strongly sericitized cores and are occasionally zoned. Brown biotite forms irregular flakes, up to 2 mm. in diameter, frequently bleached and occasionally replaced by epidote. Hornblende is present in about equal amount, typically as slightly smaller, rather ragged prisms, pleochroic brownish-green to bluish-green, occasionally chloritized. Magnetite is rather abundant as relatively coarse cubes and octahedra, associated in one case with subordinate pyrite. Quartz is restricted to interstitial grains and occasional pools, up to 5 mm. in diameter, in which any of the other minerals of the rock may be enclosed.

Similar rock types have been described by Howitt from Dargo (1887) and from Swift's Creek (1879), and by Tattam from Yackandandah. They are intermediate in mineral composition, and probably in age, between the granodiorites and the lamprophyric diorites to be discussed below, and they will be referred to again in connection with the latter.

### GRANITE

The only alkalic plutonic rock in the area definitely associated with the older intrusives is a garnetiferous granite, outcropping over a distance of about half a mile in the valley of Livingstone Creek, about five miles north of Omeo township. It includes both massive and faintly banded types, which, however, do not differ essentially in mineral composition. In a typical specimen (6673), soda-orthoclase of $2V = 60^\circ$ occurs as pools up to 5 mm. in diameter, enclosing any of the other essential constituents of the rock, which are quartz, oligoclase ($Ab_{75}$), muscovite and biotite in that order of abundance. The garnets are represented by scattered euhedral crystals, up to 1 mm. across, occasionally enclosed by orthoclase or surrounded by muscovite which tends to wrap around them.

This rock might have been derived from the more common calc-alkali types by contamination with K- and Al-rich material, but the even distribution of the garnets suggests that if any assimilation has occurred its products were already evenly distributed through the mass at the time of recrystallization. Its contacts with surrounding gneiss are poorly exposed.

## GNEISSES

The gneisses of the area may conveniently be divided into three classes. To the first belong those which are essentially sheared granodiorites and granites. To the second belong rocks which were originally granodiorite or granite but have been recrystallized. These are characterized by relative abundance of muscovite. The third class includes those gneisses containing sillimanite or cordierite, or both. Its members range from rocks which are essentially contaminated granites and granodiorites to fine-grained granular siliceous gneisses derived mainly from sedimentary rocks. The three classes are not sharply defined one from another.

### *Sheared Granodiorites and Granites*

In the rocks which have suffered mechanical deformation with only moderate amounts of recrystallization, parallelism of the inequidimensional minerals, usually without marked banding, is the rule. Owing to the very unequal resistance of the various minerals to shearing, augen gneisses are frequently developed under these conditions.

The various stages of this process are well shown by a group of specimens from a shear zone, about one mile wide, which runs N.N.W.-S.S.E. through the headwater regions of Dry Creek and Mountain Creek, across the north shoulder of Mt. Livingstone and along the northern slopes of Three-Mile Creek. The maximum diameter of the augen, which varies between 2 and 5 mm. in different specimens, depends largely on the original grain-size of the rock, and decreases only very slightly with more intense shearing. The quartz and biotite of the matrix, on the other hand, show a progressive decrease in grain-size from an average of ·5 mm. (6661) to ·05 mm. (6674, 6675). At the same time, the biotite shreds are aligned more accurately within the planes of schistosity, which conform closely to the lenticular outlines of the augen, and their finer subdivision gives a darker appearance to the hand-specimen as a whole. The augen may be composed of single andesine crystals, $Ab_{65}$ to $Ab_{55}$, or of aggregates of quartz developed from a single grain by recrystallization. In the latter case, the size of the individuals within the aggregates tends to be comparable to that of the grains of the matrix. The felspar is typically strongly zoned (6675, 6676), a combination of normal and oscillatory zoning being commonest. They may also be fractured and the fragments displaced by distances of the order of 1 to 2 mm. relative to each other. Their outline becomes more markedly lenticular in the more strongly deformed rocks (6677, etc.), and the more elongated ones tend to be rotated into a position with their longest diameters parallel to the schistosity of the matrix. Since most of the crystals are tabular parallel to the crystallographic *a-c* plane, this also results in a preferred lattice orientation, which thus does not necessarily indicate intra-granular movement.

This shear-zone, which is approximately parallel to the main schist-gneiss contact of the area and to the dominant local strike of the foliation in both schists and gneisses, appears also to have acted as a major solution channel, since pyrite has been introduced into many of these rocks and a number of formerly productive gold workings are situated along it. There has resulted sericitization of the felspars and chloritization of the biotite of some of the rocks (6679, 6680), and development of relatively abundant epidote or white mica in others (6681, 6698).

Some rocks have undergone both shearing and recrystallization. In such cases the time relationships between recrystallization and mechanical deformation can rarely be established, since the last process to persist usually obliterates all traces of the earlier ones. However, a specimen from Mountain Creek (6682) is exceptional in preserving traces of two periods of deformation. It contains porphyroblasts of slightly perthitic orthoclase in a matrix consisting of lenticles of recrystallized quartz and sericitized felspar, separated by streaks of chloritized biotite. The matrix corresponds to an augen gneiss derived from a massive igneous rock by strong shearing, although the high biotite content indicates some original contamination. The porphyroblasts contain inclusions of quartz granules and parallel orientated biotite flakes, which, however, have been rotated out of the plane of schistosity of the matrix. They were thus formed subsequently to the shearing of the rock, but were themselves rotated during a second, less intense, period of deformation.

In a rock from the Alpine Highway (6683), recrystallization after the cessation of movement can be shown to have been restricted to the crystals of andesine, $Ab_{60}$, which form augen in a matrix of quartz lenticles and sub-parallel flakes and shreds of biotite. These crystals show a clear core, surrounded by an outer zone with abundant inclusions of quartz granules and biotite flakes, orientated similarly to those of the matrix, indicating that their growth continued after the shearing responsible for the present gneissic texture of the rock had ceased.

### *Recrystallized Granodiorite and Granites*

Gneisses derived from originally homogenous massive plutonic rocks by recrystallization without significant shearing are comparatively less abundant, but provide a number of interesting types throughout the area.

Two specimens from Wilson's Creek (6684) and from the Omeo-Benambra Highway (6685) illustrate the early stages in the development of these rocks. They are characterized by the presence of perthitic orthoclase as irregular grains, up to 3 mm. in diameter, rich in inclusions of quartz blebs and small biotite flakes, and of subordinate oligoclase, $Ab_{75}$, as smaller sub-rectangular crystals. Quartz is represented by aggregates up to 3 mm. in diameter composed of numerous interlocking individuals, and the rock from the second locality also contains occasional grains of original cordierite, now represented by pinitic aggregates. Biotite forms medium-sized flakes, originally deep reddish-brown, but frequently chloritized or bleached, and shows no preferred orientation. The most distinctive feature of these rocks, however, is the very abundant development of muscovite, which initially replaces biotite or felspar, and finally forms strongly poikilitic flakes, up to 2 mm. in diameter, which enclose numerous small quartz granules and minor amounts of any of the other minerals present in the rock.

Comparable rocks also occur in the western portion of the area, a group of specimens from Rocky Valley being fairly typical (6686, 6687, etc.). These are inequigranular rocks characterized by the presence of phenocrysts of subhedral, strongly zoned andesine, $Ab_{55}$, or oligoclase, $Ab_{70}$, which may enclose quartz granules or biotite flakes in their outer zones. Orthoclase forms subordinate interstitial grains or small pools, while quartz is abundant as medium-sized irregular grains and shows only slight evidence of recrystallization. Biotite occurs as small irregular flakes, either singly or in clots, and may be extensively replaced by chlorite or epidote, or both. Muscovite forms larger but less numerous flakes and tends to be poikilitic. No sillimanite or cordierite are present in the majority of these rocks.

### *Cordierite-Sillimanite Gneisses*

These rocks predominate in the western part of the area and are only sparsely represented in the eastern and central parts. The processes of contamination and recrystallization under the action of late magmatic solutions or emanations have both operated during their development and the effects of these processes are not easily distinguishable.

The gneisses typical of the High Plains are invariably strongly heterogeneous rocks, in which banding or parallelism of the constituents are inherited from the assimilated or replaced sediments, and are not due to post-crystalline deformation. In thin sections, they are characterized by the presence of cordierite or sillimanite, or both, and in the field by the occurrence of irregular biotite-rich schlieren and of quartz-felspar nodules up to six inches in diameter. The former represent remnants of the engulfed sediments and frequently preserve primary structures in remarkable detail, while the latter are the extreme development of the felspar poikiloblasts commonly present in these rocks. These nodules may be composed essentially of one or more of quartz, perthitic orthoclase or andesine, average $Ab_{65}$. Micrographic intergrowths and myrmekite may occur at the contacts of quartz and felspar grains, and very occasional flakes of muscovite or biotite may also be present in the nodules. They are always surrounded by sheaths of almost pure biotite as relatively large flakes in good parallelism, suggesting that they resulted from the partial reconstitution of the original rock, during which the femic constituents were eliminated and re-precipitated in the immediate vicinity.

Two specimens from Mt. McKay (6688) and the road to Rocky Valley (6689) may be regarded as typical of this group. In the latter, andesine ($Ab_{60}$) is the dominant felspar, occurring as irregular crystals up to 2 mm. across, while perthitic orthoclase, as pools up to 10 mm. in diameter, predominates in the former. Quartz is the major constituent and occurs as medium-sized, irregular grains without marked evidence of recrystallization, and grains of original cordierite show various stages of alteration to micaceous aggregates or to a yellow, isotropic material. Biotite occurs as irregular flakes, without noticeable parallelism, but tending to be concentrated into bands or streaks, while muscovite forms isolated, rather larger flakes, typically strongly poikilitic. Sillimanite is invariably present, occurring as dense bundles of sub-parallel fibres when derived from biotite or as isolated needles and radiating aggregates when developed in quartz.

The nearest approach to these rocks from the central portion of the area is provided by a cordierite-sillimanite gneiss from Bingo Creek (6691) and a tourmaline-sillimanite gneiss from Day's Creek (6692), both with poikilitic muscovite and pools of alkali felspar.

Within the major masses of the High Plains type of gneiss, finer-grained gneisses richer in biotite form large schlieren and lenticles, outcrops up to 100 yards in width and half a mile in length being not uncommon. These rocks are transition types from the contaminated gneisses to the high-grade schists and some of them could equally well be classified with the latter. They differ from the typical High Plains type of gneiss in their higher biotite contents and better parallelism of the micas, accompanied usually by an increase in sillimanite and a rise in the proportion of quartz to felspar (6693, 6694).

An interesting specimen from Mt. Cope (6695) shows the preservation of small puckers of about one inch amplitude in a rock of this type. The folds are now outlined by alternate layers, composed dominantly of igneous and of sedimentary material respectively. The latter are composed mainly of biotite and sillimanite with subordinate muscovite and quartz, while the former consist essentially of quartz, poikilitic muscovite and alkali felspar, the last-named forming pools which may enclose any of the other minerals, and occasionally occurring in micrographic intergrowth with quartz. The absence of post-crystalline deformation is very clearly shown by the euhedral outlines of the biotite at the crests of the folds and by the absence of undulose extinction in the quartz.

This type of gneiss grades imperceptibly into what may be termed granular gneisses, in which sillimanite is generally absent and parallelism of the micas less marked. Lower temperature and a different physical environment at the time of reconstitution may partly account for these characteristics, but derivation from arenaceous sediments, as against argillaceous sediments for the sillimanite and biotite-rich rocks, is the main factor. Tattam called them granulites, but granular gneisses seems preferable, as they do not appear to have originated under conditions of extreme hydrostatic pressure which are thought to have characterized the development of the typical granulites in other parts of the world (Turner 1948). They illustrate various stages in the reconstitution of the original sediments by the actions of solutions or emanations, which deposited quartz and felspar, either in small clots and lenticles, or as isolated crystals, distributed uniformly through the rock. In the absence of chemical analyses, it is not possible to establish whether these newly crystallized constituents were actually introduced from nearby bodies of magma or were merely redistributed by continuous processes of solution and re-deposition as the 'ichor' made its way through the sediments. In view of the very large volume of sediments affected by these changes, the latter hypothesis, or possibly a combination of the two would appear probable.

Both banded and massive types can be recognized, frequently alternating very irregularly. The resultant complexes occupy large areas on the flanks of the major occurrences of gneisses of the High Plains type, as in the lower portion of the Rocky Valley branch of the East Kiewa River, and in the middle portions of the Bundarra River and Middle Creek valleys.

A typical specimen from Rocky Valley (6696) contains alternating discontinuous bands composed respectively of quartz and sub-parallel biotite with subordinate andesine and muscovite, and of relatively coarser-grained quartz and andesine, $Ab_{65}$. The quartz shows evidence of recrystallization under directed pressure, but the micas are free from any signs of deformation or alteration.

## Correlation and Age Relationships

The general picture of time relationships and processes of intrusion and metamorphism is in good agreement with observations elsewhere in the metamorphic belt, notably in the Tallangatta and Yackandandah districts. The earliest intrusions were emplaced by processes of granitization, resulting in large areas of gneisses of the High Plains type, flanked by zones of hybrids and granular gneisses in which the reconstitution of the sediments was less complete. Beyond these again, the sediments were extensively recrystallized to two-mica schists and nodular cordierite schists, in which the local development of sillimanite and reconstituted felspar marks areas of abnormal concentration or activity of the volatiles or solutions from the igneous masses. The attitude of the sediments was substantially preserved during the formation of the hybrids and injection gneisses, showing that the emplacement of these igneous rocks was effected by the soaking of the sediments by magmatic solutions or emanations, rather than by the forcible injection of the more viscous magma itself. (Compare Demay 1942, Dunn 1942, etc.)

Subsequent phases of igneous activity gave rise to massive rocks with sharp, transgressive contacts against both schists and gneisses. Whenever these were intruded into previously unmetamorphosed sediments, as on the west slopes of Frazer's Tableland, contact aureoles of hornfels rather than of schist were produced. These intrusions themselves, however, were still affected by localized tectonic stresses, such as those responsible for the production of augen gneisses in the Dry Gully - Three-Mile Creek shear zone, and by recrystallization under the action of local concentrations of volatiles, as in Day's Creek.

The time interval between these two major groups of intrusions cannot be established definitely. Both phases are post-Upper Ordovician, since rocks of that age are involved in the first (or regional) cycle of metamorphism. On the other hand, intrusions of the second phase are overlain unconformably by lavas and limestones of Middle Devonian age at Bindi, which set an upper limit to their possible age.

Rocks comparable to the High Plains type of gneiss have been described from southern New South Wales by Joplin (1947), who refers them to an epi-Ordovician orogeny, as contrasted with an epi-Silurian age for the massive granites and granodiorites associated with them. In the Omeo district, such a complete separation appears unwarranted, since intermediate types, representing various stages in the transition between the two extreme groups, can frequently be observed, especially in the vicinity of the main schist-gneiss contact.

## Muscovite Granite of Mount Wills

The muscovite, or pegmatitic, granite of Mt. Wills is a striking rock, which crops out intermittently in a belt about twelve miles long and six wide, extending north-westerly from Glen Wills to a point about four miles east of Mt. Bogong. At its southern and eastern boundaries it forms a number of steep slopes and escarpments, but its physiographic effect is less marked near its western extremity.

It may be regarded as a batholith crowded with major roof pendants, up to half a mile in diameter, which cover a total area comparable with that of the granite itself. It is considered to be the product of one of the final phases of that cycle of igneous activity which was responsible for the grey granites, granodiorites and gneisses, but in the absence of direct contacts its relationships can only be inferred on general grounds. The lower limit of its age is given by the fact that its contact metamorphism is superimposed on schists which had already suffered high grade regional metamorphism, showing that it post-dates at least the first phases of the main group of gneissic intrusions. An upper limit is set by the numerous dykes of the dioritic lamprophyre group to be discussed later, some of which cut the pegmatites and greisens correlated with the Mt. Wills mass (Kenny 1925a, Whitelaw, Kenny and Easton 1915). These dykes are probably Upper Devonian or slightly younger.

### *Petrology*

The rock varies from medium to very coarse-grained, frequently within the dimensions of a hand-specimen, but the mineral association is relatively constant.

In the north-western part, the less coarse-grained types predominate and the rock contains both biotite and muscovite. A typical section (6699) shows abundant orthoclase with numerous rounded blebs of quartz as inclusions, subordinate subhedral oligoclase ($Ab_{85}$), usually strongly sericitized, and abundant strongly recrystallized aggregates of quartz. Biotite forms scattered small flakes, but muscovite is more abundant, occurring as larger poikilitic flakes, faintly pleochroic, frequently distorted. Tourmaline, pleochroic dark brown to light brown, is relatively abundant, occurring typically in intergrowths with quartz.

In the south-eastern portion of the mass, the coarser-grained types are more abundant and a number of features indicate that the rocks were exposed to high concentrations of volatile constituents during the last stages of consolidation. Albite, $Ab_{95}$, is the dominant felspar, forming strongly sericitized, subhedral crystals up to 5 mm. in diameter, while the original alkali felspar is partly replaced by bluish and greenish-grey tourmaline aggregates and occasional topaz granules, or by small irregular grains of calcite (6697, 6715). Quartz again forms recrystallized aggregates, but the poikilitic character of the muscovite is less marked and biotite is absent. Pyrite is abundant as small cubes and other euhedral crystals, developed in felspar or in quartz aggregates. Occasionally, tourmaline-rich pockets within the rock contain up to 30 per cent of this mineral as small needles or prisms, up to 1 in. in length, usually in association with quartz and felspar, but not with muscovite.

Gneissic types are rare amongst these rocks, but a specimen from half a mile east of the summit (6700) shows distinct banding and parallelism of muscovite and tourmaline.

### *Contact Rocks*

The increase in grain-size and in the proportion of tourmaline, topaz and sulphides is accompanied by an increase in the contact metamorphic effects of the mass at its south-eastern extremity. In the north-western and central portions, metamorphism was restricted to the introduction of tourmaline into the argillaceous bands of the surrounding schists. This was followed by the growth of poikiloblastic flakes of muscovite, but both these changes post-dated the development of sillimanite, which is thought to belong to an earlier period of metamorphism, unconnected with the intrusion of the Mt. Wills mass.

In the vicinity of the south-eastern contacts reconstitution was much more complete, as shown by many specimens from mine dumps. Originally arenaceous beds are still essentially quartz-biotite rocks with good schistosity and only minor amounts of muscovite and tourmaline (6701, 6702), but several characteristic types of contact rock were developed from originally argillaceous beds. One of these (6703, 6704) is a fine-grained rock with well defined schistosity which has been thrown into small puckers of 1 to 2 mm. amplitude. It is composed essentially of small muscovite flakes in almost perfect parallelism, evenly distributed prisms of brown tourmaline, quartz granules and subordinate, rather poorly defined flakes of biotite. Sulphides are scattered through this rock as isolated small crystals, but never in very large quantities.

Another group of rocks (6705, 6706, etc.) is of interest as the only specimens of sedimentary origin in the area to contain andalusite. This mineral occurs as irregular grains, up to 3 mm. long, elongated parallel to the schistosity of the matrix, and readily identified by its very characteristic pink-colourless pleochroism. The crystals are crowded with inclusions of quartz granules, small biotite flakes and tourmaline prisms, all aligned parallel to the schistosity of the matrix. Occasionally these andalusites are coarsely intergrown with large, almost equidimensional flakes of strongly poikiloblastic muscovite, which pervade the rocks almost independently of the schistosity. The development of these two minerals, together with the introduction of occasional small tourmalines and scattered porphyroblasts of alkali felspar, clearly dates from a later phase of metamorphism than the reconstitution of the main mass of the rock, which is composed essentially of granular quartz, fibrolitized biotite and small muscovite flakes in good parallelism. This would suggest that andalusite requires rather higher temperatures or higher concentrations of volatile constituents for its formation than were available elsewhere in the area.

A related specimen (6707) is notable for the very marked preservation of the original sedimentary banding, being composed of sharply defined alternating light and dark layers which vary in width from about $\frac{1}{8}$ in. to 1 in. or more. The light or arenaceous bands consist of quartz and poikiloblastic cordierite as irregular crystals up to 1 mm. in diameter, together with abundant, poorly crystallized, bleached and strongly chloritized biotite and subordinate subhedral muscovite, the last two minerals showing fair parallelism, especially at the margins of the arenaceous bands. In the dark or argillaceous bands, andalusite occurs as irregular, strongly poikiloblastic individuals, up to 3 mm. in diameter, enclosing numerous small quartz granules, biotite flakes, etc. The remaining minerals in order of abundance are strongly pleochroic brown biotite, irregular to sub-rounded quartz, and occasional slightly poikiloblastic cordierite in various stages of replacement by pinite. Schistosity is not well shown in these bands, the micas tending to be aligned around the larger andalusites rather than parallel to the boundaries of the bands, and there is no evidence of mineralization or introduction of constituents from the nearby igneous rock.

A different mineral association again is shown by a specimen from a point about three-quarters of a mile E.N.E. of the summit, where it forms a xenolith or small roof pendant, measuring a few feet in diameter (6708). This rock consists dominantly of white mica, not unlike that from the surrounding granite, forming sub-parallel flakes up to 3 mm. by 1 mm., pleochroic pale greenish-brown to colourless, $2V = 30°$. In addition, it carries about 10 per cent of pale pink garnet as euhedral crystals up to 2 mm. in diameter, typically free from alteration but containing occasional small quartz granules and mica flakes as inclusions. The only other mineral present is zoisite (?), which makes up 1 per cent to 2 per cent of the rock, forming subhedral crystals up to 2 mm. in diameter, subject to clouding and alteration. Such garnet-rich assemblages have been described by Edwards (1936) as characterizing ferromagnesian-rich xenoliths at an early stage of interaction with a granitic magma, but in this case the homogeneity of the rock and the absence of granitic minerals indicate that the action of heat and volatiles alone must have been responsible for its reconstitution.

### *Ore Deposits*

The general enrichment in volatiles of the south-eastern portion of the mass is reflected in the increased number and importance of workable gold and tin deposits in that vicinity. The former are in the nature of sulphide-bearing quartz veins, concentrated in a comparatively narrow belt parallel to the main granite contact, while the latter occur as pockets and lenticles of greisen, both within the main mass of the granite and in the associated pegmatite dykes, which are rather more widespread in occurrence. Thus comparable rock types from the Mitta Mitta district have been correlated with the Mt. Wills granite by Whitelaw, Kenny and Easton (1915), and similar deposits from Wombat Creek have been recorded by Stirling (1889).

### *Dyke Rocks*

Only a few of the dykes mapped during the present investigation can be definitely correlated with the Mt. Wills granite, the most important of these being the tourmaline pegmatites, muscovite pegmatites and graphic granite dykes of Mt. Bogong, the Knocker, etc. These range up to 20 feet in thickness and can sometimes be traced for long distances, their strikes tending to coincide closely with those of the surrounding sediments. They show no features of special interest, but are rather variable in texture and in mineral contents. Perthitic orthoclase usually predominates over acid oligoclase, $Ab_{80}$ to $Ab_{90}$, the former frequently occurring as crystals several inches in diameter, especially when intergrown with quartz. Tourmaline may occur as large, well developed prisms, up to 3 in. long, as subparallel or radiating aggregates of smaller prisms and needles, or as irregular aggregates intergrown with quartz or replacing felspar. The larger prisms are frequently fractured at right angles to their long axes and the cracks infilled by quartz. Muscovite is best developed in rocks poor in tourmaline, occasionally forming books up to 1 in. square. All gradations between the various major types can be observed, but no rocks containing any of the less common minerals sometimes associated with pegmatites were found.

## PEGMATITES, APLITES AND GRANITIC DYKES

At greater distances from the Mt. Wills mass, rock types comparable to the pegmatites and graphic granites associated with that intrusion are still met with, but they occur with less characteristic types, such as aplites, and tend to form lenticular masses rather than well defined dykes. They are concentrated in two main areas on the flanks of the main gneissic intrusions. One is a belt, six to eight miles wide, which extends approximately from the Tongio Gap to Glen Valley township in the centre of the area, while the other covers the lower portion of the East Kiewa valley in the extreme western portion. Within the area occupied mainly by gneisses of the High Plains type, they are relatively rare, and it is probable that their place is taken by the previously described leucocratic nodules in these gneisses, which would account, cumulatively, for a comparable volume of acid differentiates.

It is not usually possible to correlate any of these dykes with particular plutonic masses, but their relative ages can sometimes be established by comparing the amount of recrystallization which they have undergone. They are sometimes difficult to separate from the younger group of dykes associated with the Red Granite orogeny, but the latter appear to be restricted to an area relatively close to the main mass of the Red Granite and frequently show mineralogical peculiarities which assist in their identification. In addition, the acid differentiates of the older group frequently form rather larger masses and tend to grade into the adjacent ortho-gneisses instead of showing transgressive relationships to them.

Tourmaline-bearing types are not very abundant in this group, notable exceptions being a pegmatite from Bingo Creek (6709, 6710) and a more strongly recrystallized rock from Livingstone Creek (6711). The former also contains a number of small subhedral garnets enclosed in larger grains of slightly perthitic orthoclase, suggesting a possible relationship to the garnetiferous granite of Livingstone Creek.

By a decrease in the amount of mica present, these pegmatites grade into veins of graphic granite, comparable to those already described in connection with the Mt. Wills granite. The extreme types are represented by rocks in which individual orthoclase crystals attain an average diameter of several inches and the enclosed quartz blebs are in optical continuity over comparable areas (6712, 6713, etc.).

Another very important type is represented by rocks which are most conveniently referred to as coarse-grained aplites, since they are characterized by the mineral association and texture of aplites, although the average grain-size may reach 2 mm. or more. A rock from the S.E.C. road to Rocky Valley (6714) illustrates this type. It contains perthitic orthoclase, acid oligoclase, $Ab_{85}$, and quartz in approximately equal amounts, together with rather less abundant muscovite, all the constituents occurring as equant, anhedral grains of about equal size.

With increasing amounts of recrystallization, these rocks grade into types which can only be distinguished from the major masses of granular gneiss by the absence of contamination effects, by the composition of their felspar, which is albite ($Ab_{90}$ to $Ab_{95}$), and by their more homogeneous appearance in large outcrops. Two rocks from Wilson's Creek are of this type (6716, 6732), differing from the previous one essentially in the presence of small chloritized biotite flakes in about equal amounts to the muscovite, and in the incipient recrystallization of the original quartz individuals to aggregates of smaller grains.

Similar relationships hold in the case of the finer-grained aplites, the more strongly recrystallized equivalents of which locally form relatively large masses, as on the north shoulder of Mt. Livingstone and on the spur running north-west from Timm's Lookout. At these localities, recrystallized aplites outcrop over areas of at least half a mile by half a mile and the occurrences appear to date from one of the earlier phases of the igneous cycle.

One of the specimens from the former locality (6717) is notable for the presence of andalusite, which occurs as clusters of small platy and prismatic crystals closely associated with flakes of biotite in various stages of bleaching, or as isolated crystals enclosed by large alkali felspars. A specimen from a smaller outcrop in Mountain Creek (6718) also contains andalusite, originally occurring as crystals up to ·5 mm. long, but now partly altered to fine-grained aggregates of white mica.

Hills (1938) has suggested that andalusite may, under certain conditions, crystallize from an uncontaminated magma, but since there is here abundant evidence of contamination in many of the associated plutonic rocks, these occurrences of andalusite are probably due to the assimilation of aluminous sediments by the hypabyssal rocks concerned. The derivation of the mineral from xenocrysts is excluded by its complete absence from the country rock in the vicinity of these intrusions.

Another group of rocks which may be classified with the above is represented by a granite (6719) and two granodiorite dykes (6720, 6721), which form small masses in the lower portion of Day's Creek. These rocks are similar in thin section to specimens of the slightly recrystallized plutonic rocks from some of the larger occurrences, but their appearance in the hand-specimen is characteristic. The granodiorites especially, being composed essentially of clear quartz, deep-green chloritized biotite and pink to flesh-coloured felspar, present a striking colour scheme. Mineralogically, their main distinguishing feature is the presence of unzoned, rather strongly sericitized albite, $Ab_{90}$, side by side with zoned, less altered oligoclase, $Ab_{70}$, the former occurring as larger but less numerous crystals than the latter, so that their total amounts are approximately equal.

## TAMBO FORMATION

### GENERAL

The Tambo Formation of reddish and purplish shales, sandstones and conglomerates occupies an area of approximately six miles by four miles, elongated in a north-south direction and centred on the peak from which it takes its name. It was first described by Selwyn (1866), who recorded indistinct plant impressions from it, and more detailed accounts of its lithology and field relations were given by Howitt (1876) and Gaskin (1942). Only the northern portion of the occurrence was studied during the present investigation, but a number of new relationships were observed and new interpretations were given to several features previously observed by other workers.

The various lithological types alternate rapidly, individual beds varying widely in thickness and occasionally reaching 30 ft. to 40 ft. in the case of the coarser conglomerates. The dominant pebbles and boulders, which range up to 18 in. in diameter in some of the beds, are quartzite and reef quartz, with schists subordinate and igneous rocks almost absent, except in the basal conglomerate to be described below. The grits are characterized by poor sorting of the grains according to size and by the abundant presence of angular quartz (6722). Even the finest grained shales contain scattered angular quartz grains, and all indications are for rapid sedimentation under comparatively shallow-water conditions.

The strikes of the beds remain sensibly constant throughout the northern portion, varying between 340° and 360°. The dips are likewise uniform for the major portion of the series, ranging from 30° to 50° to the west and south-west, and showing a gradual increase from east to west. In the extreme west, however, approaching the contact with the granite porphyry of Mt. Sisters, the dips increase more rapidly and the beds locally appear to be vertical or dipping to the east at a high angle. The interpretation of these structures is made extremely uncertain by hillside creep and the masking of outcrops by hillwash, but their possible significance will be referred to later.

The thickness of the whole series was estimated at 1000 ft. to 1200 ft. by Howitt (1876), but the present work would suggest a total of not less than 2000 ft. and possibly rather more. The uncertainty in these figures is largely due to the difficulty of obtaining representative values for the dips of the most westerly outcrops.

A single occurrence of an interbedded flow or narrow sill was encountered on the west slopes of Mt. Tambo and could be traced for about half a mile parallel to the strike. The rock is best described as a rhyolite, containing occasional fractured and embayed phenocrysts of quartz and scattered small xenoliths of schist and quartzite in a cryptocrystalline matrix, in which the only identifiable components are abundant minute flakes of white mica. The rock shows a tendency to parallel elongation of the phenocrysts and xenoliths, suggesting flow structure, and the microlites of the matrix are aligned in two sets of planes whose acute bisectrix coincides with the direction of elongation of the larger particles (6724, 6725). The average thickness of the flow or sill is of the order of 30 ft., but no metamorphism of the sediments in contact with it could be detected.

No satisfactory palaeontological evidence for the age of this formation could be obtained. Previous records are restricted to the above-mentioned plant-beds (Selwyn 1866, Stirling 1887d, etc.). The latter mentions Sphenopteris amongst the forms present, but his specimens have not been preserved and some doubt had been thrown on the existence of these beds by subsequent workers (Gaskin 1942). The only other fossil obtained from this series was an indeterminate fish-plate collected by Broadhurst and Campbell in connection with their study of the Mt. Leinster complex.

In the course of the present investigation, plant remains were obtained at three localities, aligned practically parallel to the strike of the beds, and preserved in a very similar matrix, so that the existence of an extensive fossiliferous horizon is indicated. The most southerly of these occurrences, within five chains of the summit, is probably the one described by previous workers. At each locality, narrow stems and strap-like leaves, up to $\frac{3}{8}$ in. wide, are embedded in a matrix of yellowish or bluish micaceous shale, associated in one case with a single sporangium (?) of about $\frac{1}{4}$ in. diameter.

All these remains are unfortunately quite indeterminate, so that the age of the formation still rests on correlations based on lithology and structural features alone.

### Field Relationships

At its north-eastern boundary the series rests with an angular unconformity on the schists and gneisses of the Omeo series, and a basal conglomerate is exposed on one of the spurs running into the East Branch of Tambo Gully. This contains abundant boulders and angular fragments of the schists and gneisses, up to 2 in. in diameter, and grades upwards into normal conglomerates over a thickness of some 40 ft. to 50 ft. Further south along this boundary no trace of this bed is visible, and it must be assumed that minor faulting has taken place, since the actual contact is usually sharp and well exposed, the two series outcropping within a few feet of each other.

On the west the Tambo Formation is in contact with the granite porphyry of Mt. Sisters. Stirling (1887) claimed that the porphyry intruded the sedimentary rocks, but Howitt (1876) and Whitelaw (1898) considered the sedimentary rocks were the younger. The present work supports the view that the porphyry is intrusive because it has proved the existence of a metamorphic aureole in the Tambo Formation.

Less altered rocks of the aureole occur immediately north of a prominent saddle on the main ridge, about one mile and a quarter north of the summit of Mt. Tambo. They have lost the characteristic red or purple colour of the unaltered rocks and their constituent grains are much more firmly cemented, so that they are virtually quartzites or cemented conglomerates. In thin section, however, very little evidence of recrystallization and secondary growth of the clastic particles are visible (6726-6729). Westward toward the granite porphyry these changes become more marked and the rocks approach true hornfels in appearance, assuming a blue-grey tint and greatly increasing in hardness. The actual contact with the porphyry is poorly exposed but appears to be an approximately straight line.

A number of included blocks of metamorphosed Tambo Formation, ranging in size from a few yards to ten chains, occur in the main mass of the granite porphyry. They are concentrated in a belt about a mile long and half a mile wide, running almost due west from the main contact through the low saddle between

Mt. Sisters and Mt. Pleasant. Although some of the hornfelses in this belt might have been derived from the low-grade schists outcropping to the north-west, the presence of metamorphosed conglomerates and coarse grits among them indicates that most of them belong to the Tambo Formation. The metamorphism shows no special features, the matrix of the conglomerates behaving as would a homogeneous rock of comparable texture and composition, while the larger fragments, being derived dominantly from quartz reefs and arenaceous sediments, tend to be less affected. Biotite is abundantly developed as squat, subhedral flakes in random orientation, quartz shows a tendency to the development of outgrowths in optical continuity with the primary clastic grains, and a few poikiloblastic aggregates of intimately associated small flakes of white mica and of chlorite may represent the alteration products of cordierite (6730, 6731).

Further south the boundary is a fault, unmetamorphosed members of the Tambo Formation abutting directly against granite porphyry. In the saddle of the main divide, about a mile and a half west of the summit, interbedded shales and sandstones show variable dips, ranging from 70° east through vertical to 70° west, but the strikes, which are parallel to the contact, remain uniformly at 340° to 350°. In some outcrops, though not always the ones nearest the junction, closely spaced, approximately vertical, shear-planes can be recognized, also striking parallel to the junction and giving a rough type of fracture cleavage to the rocks. The granite porphyry near the junction shows analogous shear-planes, marked by granulation, neo-crystallization, or both, occasionally with discernible movement (6840).

This junction is evidently part of a major fault which is possibly the northern continuation of the western boundary fault of the Bindi Limestones, mapped by Gaskin.

A second fault, running east-west through the previously mentioned saddle north of the summit, separates this main mass of the Tambo Formation from its metamorphosed equivalents to the north, and forms the second boundary of the fault block. The third, eastern one, is formed by the previously mentioned fault or faults north-west of the summit, which must be assumed to account for the absence of the basal conglomerate at the southern portion of that boundary.

No direct evidence as to the age of these faults is available, but they do not determine present physiography, so they must considerably pre-date the ?Pleistocene movements on the Livingstone Creek and Mountain Creek faults. They may tentatively be classed with the thrusts and faults of the Bindi district, to which a probable late Devonian or epi-Devonian age was assigned by Gaskin.

Structurally, the Tambo Formation thus comprises two distinct units in this area: the northern portion which overlies the schists and gneisses of the basement complex with an angular unconformity and is metamorphosed by the Mt. Sisters granite porphyries, and the larger southern portion which is bounded by faults on the east, north and west, but which overlies the Bindi limestones conformably at its southern extremity (Gaskin 1942).

### Age

In the absence of conclusive palaeontological evidence, the age of the Tambo Formation must be established by correlation with lithologically similar beds from other parts of eastern Victoria, and by the use of its relationships to the Bindi Limestones to the south.

Gaskin, using the contact relationships at Mt. Waterson and Scrubby Creek, concluded that the Tambo Formation rested on the Middle Devonian Bindi Limestones without any marked angular unconformity and assigned an Upper Devonian or late Middle Devonian age to it. The evidence of correlation with structurally and lithologically similar occurrences in eastern Victoria tends, on the whole, to support this view, as will be shown in a later section.

The only other suggested correlation of the Tambo Formation is with the Kerri series of grits, sandstones and conglomerates in central Victoria (Thomas 1932), but since this latter series is only known to be younger than Upper Ordovician and older than epi-Devonian granodiorite, this does not throw any new light on the age of the eastern Victorian occurrences.

### Wombat Creek Formation

The Wombat Creek Formation of shales, sandstones, limestones, grits and conglomerates in the extreme north of the area was examined only cursorily during the present work. It has been the subject of numerous previous reports and of several conflicting age determinations.

The beds dip much more steeply than either the Tambo Formation or the Bindi Limestones, dips of 70° to 80° being the rule and vertical dips not uncommon. As a result, their boundary against the low-grade schists to the west and south-west is based entirely on the incoming of lithologically distinctive beds, especially conglomerates and limestones, there being no apparent structural break between the two formations.

To the north the beds are overlain by 400 feet of fragmental rhyolites and silicified tuffs (Kenny 1937e), which are the southern extension of the Mt. Benambra mass described by Edwards and Easton (1937). To the south, its contact relationships are masked by the Newer Basalt flows of Frazer's Tableland and Morass Creek. Stirling (1887) recorded bosses of quartz porphyry (= granite porphyry), intrusive into these beds, and Whitelaw (unpublished) has mapped a granitic intrusion in the Mitta Mitta valley about three miles upstream of the Wombat Creek junction. The former, together with the occurrence at Gresson's Knob (see below), are closely comparable to the Mt. Sisters masses, but the latter was found to be an aplite-pegmatite-porphyritic granite complex which cannot be definitely correlated with any other igneous rock of the area.

The general structure appears to be anticlinal, with the main axis running approximately N.W.-S.E. through the vicinity of the Morass Creek-Gibbo River junction. Both the strikes and dips frequently change very abruptly and evidence of shearing is locally very marked (Whitelaw, unpublished; Kenny 1937e).

The fossils were first described by Ferguson (1899), and later in more detail by Chapman (1912, 1917, 1920). The former suggested an Upper Silurian age for the whole series, while Chapman referred a number of localities to the Middle Devonian and the remainder to the Yeringian, then regarded as Upper Silurian. There is no field evidence for any major break within the series, and it seems likely that facies differences, rather than differences in age, are responsible for the variations in the fossil assemblages.

### Limestone Creek Formation

The Limestone Creek Formation, comparable in many respects to the Wombat Creek Formation, does not occur within the area, but a brief reference must be made to it for purposes of correlation. It covers relatively large areas in Limestone

Creek, Dead Horse Creek, Native Dog Creek, Stony Creek and Cowombat Creek, all situated from 15 to 30 miles east and north-east of Benambra township, but the various occurrences have not been correlated in detail. Chapman (1920) again refers some of them to the Middle Devonian and others to the Yeringian, but probably with no more justification than in the case of the Wombat Creek series.

Relationships are complicated by the fact that some members of the formation rest on volcanic and pyroclastic rocks, probably of the Snowy River Series, while others are overlain or intruded by apparently identical types. In the past, this has been explained by postulating two groups of limestones (Whitelaw, unpublished), but in the light of relationships at Bindi and Mt. Tambo it appears more probable that the sediments belong to one series only, and that the younger group of igneous rocks is to be correlated with the granite porphyries of Mt. Sisters, etc.

## Trachyte-Syenite Complexes

Trachytes and syenites occur at several localities in the eastern part of the area, notably Mt. Brothers, McFarlane's Lookout, Pendergast's Lookout and Mt. Little Tambo, and at Frenchman's Hill near Omeo. They usually form prominent peaks or groups of peaks in which jointing is largely responsible in determining the slope, which is roughly constant for any particular mass. At Mt. Brothers, for example, a major set of joints striking approximately N.W.-S.E. and dipping steeply to the north-east, has given rise to extensive cliffs facing the junction of Morass and Benambra Creeks. The 700-ft. cliff of McFarlane's Lookout has been similarly caused.

They are grouped together because of petrological and structural similarities and form part of a series of alkaline intrusives, lavas and pyroclastic rocks, of which the full extent is unknown. Including Mt. Leinster, mapped by Broadhurst and Campbell (1932), where this distinctive suite was first recognized, these rocks outcrop over a total area of at least 40 square miles, the occurrences being distributed over an area of approximately 20 miles by 15 miles, and there is every possibility of other occurrences being discovered in the upper reaches of the Buchan River to the east of the area under discussion, and in the headwaters of Beloka Creek and the Gibbo River to the north-east. In addition, since the plutonic and hypabyssal phases of this suite are connected by transitional types with corresponding rocks of the granite porphyry group, the area occupied by these rocks would be increased considerably if these transition types, which are here grouped with the granite porphyries, were also taken into consideration.

### Trachytes

The trachytes associated with these complexes show considerable diversity of texture, but a relatively constant mineral association. However, since they invariably preceded the plutonic phases, they have frequently undergone secondary changes due to metamorphism by the latter.

Specimens from the Mt. Leinster complex revealed no new features beyond those observed by Broadhurst and Campbell. Both flows and pyroclastics are present, but most of the specimens examined belong to the former group. They are dominantly fine-grained porphyritic types, containing variable numbers of phenocrysts of orthoclase, anorthoclase, or both, up to 2 mm. in diameter, although occasional crystals may reach 5 mm. Pale green augite, aegirine-augite, brownish-green hornblende and deep brown biotite are the characteristic ferromagnesian minerals, having crystallized in that order (6761, 6762). The matrix consists essentially of the same minerals, with the addition of quartz as relatively large, irregular blebs in one specimen (6763). The texture is typically trachytic, although flow structures are only rarely discernible in the hand-specimen. Granular texture is less common (6763, 6764). The effects of contact metamorphism were not studied in detail in this complex, but the precipitation of finely divided iron ores within the original ferromagnesians, as described by Broadhurst and Campbell, is readily observed (6765).

Specimens from Morass Creek, north-west of McFarlane's Lookout, and from Pyroclastic Hill, east of the Marengo Gap, are closely comparable to the above described types.

Pyle's Deposit is an impure replacement limestone situated on the south-west slopes of Mt. Brothers and may conveniently by used as a locality name for a small group of trachytic rocks in which it occurs. Most specimens of these conform closely to the types already described from Mt. Leinster (6766, 6768), but minerals indicative of excess alkalies, such as aegirine-augite, are typically absent, their place being taken by an increased proportion of biotite. Pyroclastics are relatively less abundant, but occasionally examples do occur (6769). A probable dyke rock is represented by a relatively coarse-grained specimen (6770) in which the original ferromagnesians have been largely replaced by fine-grained aggregates of epidote, and in which numerous radial aggregates of alkali felspar have been developed, the individual components of the latter being laths up to 1 mm. long and ·1 mm. wide.

A rock from the same locality, but represented only by a group of boulders in the gully just north of the limestone outcrop, differs from the previously described types in that oligoclase, $Ab_{75}$, predominates over alkali felspar among the phenocrysts, which tend to be grouped into small clots, giving a glomero-porphyritic texture (6771). Colourless augite rimmed by biotite, subordinate green hornblende and abundant euhedral biotite, originally deep brown, now partially bleached and crowded with minute granules of iron ore, also occur as phenocrysts, all up to 1·5 mm. in diameter. The matrix is markedly trachytic, with alkali felspar predominant.

In addition to the normal contact phenomena, a number of rocks from this locality show various stages of pneumatolytic alteration and replacement. The rocks concerned were originally fragmental trachytes and ash beds, situated about half a mile from the nearest syenite outcrop. Two beds in particular have been affected. One strikes 125°, dipping 70° N.E., while the other, approximately half a chain to the south, strikes 115° and is vertical. The replacement of these beds has given rise to what is locally called Pyle's limestone deposit, first recorded by Whitelaw (1913, unpublished) but described by him as a limestone interbedded with the low-grade schists and overlain unconformably by the trachytes. This is the only locality in the area where dips and strikes can be measured on any members of the trachyte series, and the values obtained suggest that the series has undergone intense deformation and is structurally complex. It is also of interest that these strikes are almost at right angles to those of the nearest occurrences of schist, but with the limited data available the interpretation of the structure cannot be attempted.

One of the replaced beds was originally a medium-grained, porphyritic trachyte, containing phenocrysts of alkali felspar up to 3 mm. long and micro-phenocrysts of euhedral deep-brown biotite, up to 1 mm. in diameter, in a granular matrix of alkali felspar (6772). Small clots of magnetite crystals and euhedral apatites, both up to ·5 mm. in diameter, are scattered through the rock and appear to be primary. This trachyte passes locally into a rock composed essentially of fragments, ranging in size from about $\frac{1}{2}$ in. down, which consist of siliceous or trachytic material or of the fragments of larger crystals, including quartz, felspar and biotite (6774). The other bed was very much finer-grained, probably an ash-bed, and shows closely-spaced bands, somewhat contorted, which appear to be a primary feature (6773).

Alteration in the coarser-grained bed is restricted to the local replacement of felspar and ferromagnesian minerals by quartz-calcite-clinozoisite aggregates and by magnetite-chlorite-clinozoisite aggregates respectively, and to the introduction of minor amounts of pyrite, galena and chalcopyrite. In the other bed, replacement is more nearly complete, resulting in a rock composed essentially of finely granular calcite and clinozoisite, again with minor amounts of sulphides. The banding is due to variations in the proportions and grain-size of the two major constituents, and the bed contains occasional pockets and lenticles composed almost entirely of coarsely crystalline calcite with an average grain-size of about 1 mm., occasional individuals growing to as much as 1 cm. The larger of these pockets were formerly quarried and burnt for lime, but no work has been done in this locality for a number of years and the extent of the deposit appears to be strictly limited.

The central portion of Mt. Brothers is also composed of rocks which may be correlated with the occurrences described above, consisting essentially of medium-grained, only slightly porphyritic types which in many respects are intermediate between the true trachytes and the syenites. These rocks are regarded as the hypabyssal representatives of the suite, and it is probable that detailed mapping would reveal a number of distinct minor intrusions. They occupy the relatively low-lying area between the north and south peaks of Mt. Brothers and are readily distinguished in the field by their tendency to weather into relatively small angular blocks, as opposed to the larger, well rounded tors of the syenite.

At Mt. Little Tambo is the largest single occurrence of trachytic rocks. It has been referred to as granite by Stirling (1887d), but is not shown on the sketch-map of Hinnomunjie Parish by Whitelaw. Only relatively small outcrops of syenite are exposed at this locality, but the trachytes have undergone metamorphism comparable to that of the other complexes, and it seems probable that the plutonic phase underlies the whole occurrence at no great depth.

The rocks are typically strongly porphyritic types, containing phenocrysts of both orthoclase and andesine, the latter varying from $Ab_{65}$ to $Ab_{55}$. The matrix may be relatively coarse-grained and rich in quartz, in which case biotite is the dominant ferromagnesian (6775), or finer-grained and almost entirely felspathic. In the latter case the ferromagnesians are purplish augite with subordinate greenish hornblende and brown biotite among the phenocrysts and aegirine-augite and biotite in the matrix (6776, 6777). One of these specimens (6776) is crowded with cognate fragments, while the other is homogeneous. In both rocks, changes in the physical environment are indicated by the presence of rounded magnetite granules rimmed by small biotite flakes in radial arrangement, and of rounded and embayed plagioclase phenocrysts, veined and penetrated by material of the matrix. The primary origin of these structures is suggested by the absence of recrystallization in other minerals of the rock, such as would be expected if contact metamorphism had been responsible for these reactions.

The Frenchman's Hill complex is the smallest in the area, but shows practically all the features observed in the other occurrences and contains a great variety of rock types. Fragmented rocks are very abundant (6778-6780, etc.), ranging from normal agglomerates to flows crowded with xenoliths. The majority of the fragments are trachytic and can be distinguished only by differences in texture and/or grain-size, but arenaceous types are not uncommon and occasional ones correspond to rocks originally rich in ferromagnesian minerals. The last-named type are always recrystallized with the formation of granules of iron ore, small euhedral flakes of brown biotite and/or even smaller squat prisms of green hornblende. It is usually impossible to determine whether this is due to reaction with the trachyte matrix or to subsequent metamorphism by the syenite, since the matrix does not show any evidence of recrystallization until a fairly advanced stage of metamorphism is reached.

Among the massive rocks, it is not usually possible to distinguish extrusive from intrusive types, but the field relations of some of the phases at the western and north-western extremities of the complex suggest that dykes and small bosses were locally important and may exceed the extrusive phases in extent over small areas. Porphyritic types, with phenocrysts of slightly perthitic orthoclase, up to 2 mm. long, predominate, and the matrix may be trachytic (6781), or granular (6782), and may contain minor amounts of interstitial quartz (6783). Magnetite is usually the only primary ferromagnesian mineral present, although the occurrence of abundant irregular aggregates of minute epidote granules indicates that one or more other dark minerals were originally present in some of the specimens (6784, etc.).

With an increase in alkali contents, these rocks pass into the types described as solvsbergites by Skeats (1912) and later workers. They are characterized by the presence of aegirine, pleochroic deep green to yellowish green, and riebeckite. pleochroic deep blue to greenish blue (6785-6787). These minerals occur only as interstitial grains or strongly poikilitic crystals, and are never very abundant. The matrix is always granular and very rich in an untwinned alkali felspar (?orthoclase), characterized by the presence of very well developed striations, due to the presence of very fine lamellae of slightly different refractive index, probably albite, which are always arranged parallel to an extinction direction of the crystal. Quartz is always present, although in small amount. Magnetite and rare biotite are the only other dark minerals, and sphene is the most abundant accessory.

The metamorphosed equivalents of all these types can be recognized in various stages of alteration. The breaking down of the ferromagnesian minerals, especially biotite, with the precipitation of numerous minute granules of iron ore, occurs at an early stage (6788). This is followed by the development of small irregular flakes of brown biotite and subhedral crystals or squat prisms of green hornblende scattered through the rock, probably by a redistribution of material from original xenoliths rich in dark minerals (6789, 6790). Fluorite is occasionally present in small amount, both in the matrix and in association with arenaceous xenoliths. The matrix also shows evidence of recrystallization, areas of clear, slightly coarser-grained felspar replacing portions of the originally finely granular aggregates of cloudy ?orthoclase. The striations are, if anything, even more marked in the recrystallized material than in the original matrix (6790, etc.). At the same time, the phenocrysts tend to extend by forming outgrowths in optical continuity with the original crystals (6791), which may give rise to a marginal zone crowded with inclusions of material from the matrix. Quartz is also redistributed and possibly introduced in part from the syenite, giving rise to pools, up to 2 mm. in diameter, in which any of the other minerals of the rock may be enclosed (6791).

Smaller masses of trachytic rocks also occur at Mt. Bung Bung, south-east of Benambra township, at Morass Creek, north-west of McFarlane's Lookout and at scattered other localities, but these occurrences show no features of special petrological or structural interest.

## SYENITES

Syenitic rocks form part of every one of the previously listed trachyte-syenite complexes, and they are grouped together because of similarities in mineral contents and mode of occurrence. The most easterly masses, except for Mt. Leinster itself, are those of McFarlane's Lookout and Pendergast's Lookout, about ten miles north-east of Benambra township, which were mapped by Broadhurst and Campbell as part of the Mt. Leinster complex. About four miles north of Benambra another mass occupies an area of about 15 square miles, forming the northern and southern peaks of Mt. Brothers, and small outcrops are also associated with the complexes centred on Mt. Bung Bung and Mt. Little Tambo.

In the central portion of the area, the only occurrence of rocks of this group is the isolated, much smaller mass which forms the core of the Frenchman's Hill complex, about two miles north of Omeo.

Heavy mineral analyses of the syenites, as well as of the granite porphyries and granites to be described later, appear in Table 1. Rosiwal analyses appear in Table 3.

A rapid re-examination of the most easterly complexes gave results in general agreement with those of Broadhurst and Campbell. The rocks are pale grey in the hand-specimen, weathering reddish, and are not markedly porphyritic. Perthitic orthoclase makes up the bulk of the rocks, occurring as crystals up to 4 mm. in length, always anhedral, either sub-rounded as in a specimen from Mt. Leinster (6793) or interlocking as in a rock from McFarlane's Lookout (6792). The amount of quartz varies from a trace (6792) to that of a major constituent. Its habit is always interstitial, but occasionally it forms coarse micrographic intergrowths with alkali felspar, as in a rock from the west bank of Morass Creek opposite Pendergast's Lookout (6794). The ferromagnesian minerals, as pointed out by Broadhurst and Campbell, are extremely variable. Magnetite, pale green augite, aegirine-augite, green hornblende and strongly pleochroic brown-black biotite are present in most specimens, having crystallized in that order, since any of them may be surrounded by any of the later-named ones. The crystals are typically subhedral, ranging up to 2 mm. in diameter, and are usually enclosed by the alkali felspars. In addition, one specimen (6793) shows purple, non-pleochroic augite side by side with the greenish variety, both being sometimes rimmed by aegirine-augite. Broadhurst and Campbell also record bluish hornblende in one rock (2618), which appears to be riebeckite.

Broadhurst and Campbell referred to these rocks as pulaskites and nordmarkites, according to the amount of quartz present. The type pulaskite from Arkansas, however, contains nepheline both in the mode and in the norm, whereas the rocks of the Mt. Leinster complex are never quite free from quartz. The name is thus not appropriate and the rocks are best referred to simply as soda-syenites and quartz syenites.

The Mt. Brothers mass is rather more variable in texture and mineral composition, ranging from soda-syenite to soda-granite, and including both porphyritic and even-grained varieties. The south-eastern and north-eastern portions of the mass, including all the main peaks, are strongly porphyritic, containing sub-rectangular phenocrysts of alkali felspar, up to 2 in. in length, and have been described as a porphyritic granite (Whitelaw, 1898). The phenocrysts are orthoclase, which is locally faintly perthitic or encloses scattered blebs of plagioclase in optical continuity with each other. In the hand-specimen, they show marked schiller on the (100) faces, identified by the acute bisectrix figure obtained from sections cut parallel to this plane. This also coincides with a rough parting and a slight elongation of the crystals to give an approximately tabular form.

Plagioclase also occurs independently as subhedral, zoned crystals up to 5 mm. long, ranging from oligoclase, $Ab_{75}$ (6798), to andesine, $Ab_{65}$ (6796), although some of the material exsolved from the perthites may be more sodic. It is always subordinate to the alkali felspar, but the difference is not very considerable, so that some of the rocks may be referred to as monzonites and adamellites. Quartz is always present, either as irregular grains, forming part of the matrix, or in micrographic intergrowths with some of the smaller alkali felspars and with the marginal portions of the phenocrysts. Magnetite, greenish brown hornblende and deep brown or greenish brown biotite are the only ferromagnesian minerals present, occurring in much the same way as in the Mt. Leinster rocks. Sub-rounded apatite and euhedral zircon and sphene are important accessories, usually closely associated with small clots of the ferromagnesian minerals.

An interesting specimen is provided by a partiallly assimilated xenolith of trachyte near the south-western border of the mass (6799). The xenolith has been reconstituted so as to contain a mineral assemblage similar to that of the syenite itself, with the addition of purplish augite which forms rounded grains, rimmed by aegirine-augite or by hornblende. The average grain-size of this specimen is only about 2 mm. and phenocrysts are absent, the alkali felspar forming a mosaic of interlocking grains which frequently enclose some of the smaller crystals of the dark minerals. Quartz is present in traces only, but apatite is relatively abundant, forming numerous slender needles enclosed by the felspar.

Along the west and north-western borders of the mass the rocks are more closely comparable to those of McFarlane's Lookout and Mt. Leinster. No phenocrysts of alkali felspar occur, and quartz is less abundant (6800). At these points, exposures are not sufficient to show the contact relationships between the main mass and the non-porphyritic types, but occasional sharply defined pockets of the coarser-grained phase, up to a few chains in diameter, occurring within the finer-grained rocks, suggest that the former is the younger of the two. This is confirmed by relationships north-east of the main peak, where a tongue of the porphyritic variety crosses Morass Creek and comes into contact with the finer-grained rocks of McFarlane's Lookout. Near the contact, the phenocrysts become less abundant and are concentrated into small clots. At the same time, veins and lenticles of fine-grained aplite and occasional ones of graphic granite appear, cutting both rock types indiscriminately. No sharp boundary can be traced, but the relationships suggest that the porphyritic phase is the younger, being possibly intruded before the complete consolidation of the even-grained phase, so that some intermingling of the magmas took place.

This interpretation is in agreement with the observations of Broadhurst and Campbell, who described scattered pockets of coarser-grained rocks, believed to represent late phases, interspersed with the even-grained rocks of McFarlane's Lookout. The differences between the two types, including the greater abundance of quartz and of acid plagioclase, and the absence of pyroxenes in the porphyritic phase, can all be accounted for if the latter is regarded as the product of consolidation of a residual magma, relatively enriched in silica, soda and mineralizers.

At Mt. Bung Bung and Mt. Little Tambo syenites comparable to both the even-grained and the porphyritic varieties of Mt. Brothers occur, but the total area covered by these masses is only of the order of three to four square miles. The rocks do not differ in any essential way from their above-described counterparts, but purplish augite and epidote are present in the porphyritic phase (6859), which is rather poorer in quartz than the corresponding rock from Mt. Brothers, and the even-grained phase tends to be rather richer in dark minerals, including magnetite, greenish-brown hornblende and deep brown biotite than corresponding rocks from elsewhere in the area (6802, 6829).

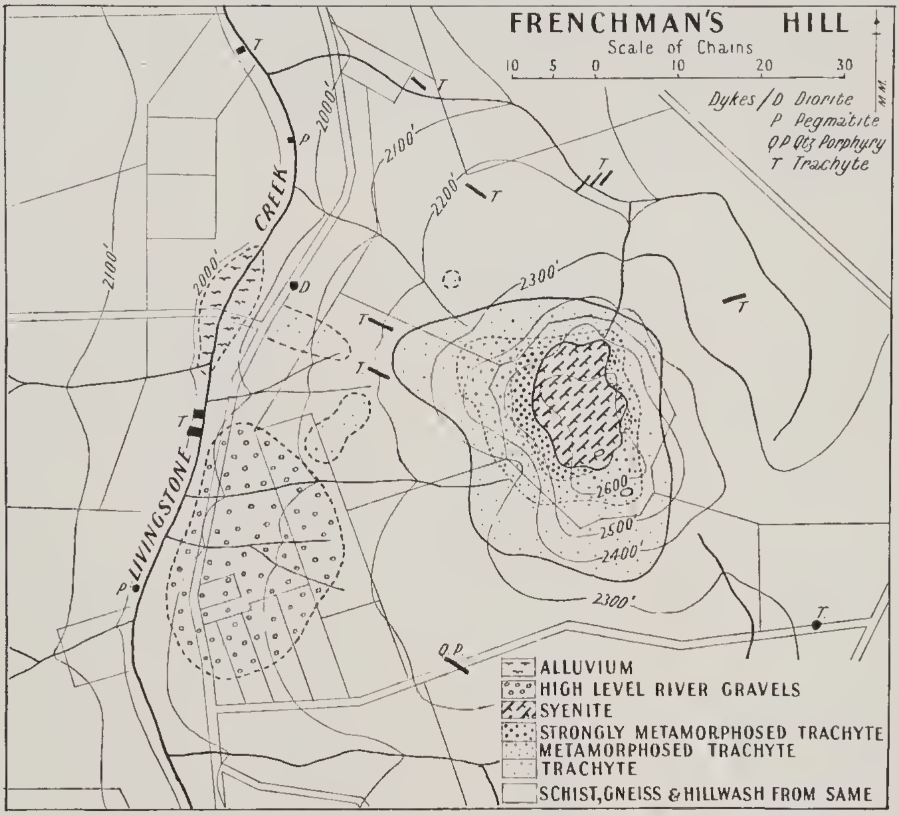


Fig. 4.—Geological Map of Frenchman's Hill.

One very distinctive type (6803) differs from all other comparable specimens in showing a strong tendency for the orthoclase felspars to develop an interlocking texture and to enclose numerous small blebs of a component of slightly higher refractive index but of the same birefringence and extinction of the host (albite ?). The ferromagnesian minerals of this rock are essentially greenish-brown hornblende and occasional granules of iron ore, both of which may be rimmed or partly replaced by small elongated flakes of biotite. No quartz appears to be present.

The only other occurrence of syenitic rocks within the area is that of Frenchman's Hill, occupying an area of only about 200 yards by 200 yards (6804, 6805).

The mass was first described by Howitt (1890), who referred to these rocks as orthoclase porphyries and compared them to similar types from Mt. Leinster. Skeats (1912) referred to them as solvsbergites 'approaching a plutonic habit,' and implied a gradation from them into the surrounding trachytes, which, however, has not been confirmed by the present observations.

The rocks consist dominantly of subhedral crystals of orthoclase. up to 5 mm. in diameter, enclosing occasional blebs of sodic oligoclase, $Ab_{85}$, or albite, $Ab_{90}$, in parallel orientation. Quartz forms smaller, subhedral grains and also occurs in micrographic intergrowth with the alkali felspar to form the matrix of the rock. The felspar of these intergrowths is frequently in optical continuity with one of the adjacent larger crystals, but the preservation of the crysal form of the latter shows that the crystallization of the matrix was separated from that of the phenocrysts by a definite interval of time. Biotite and iron ore are the only ferromagnesian minerals occurring in the rock, the former as clots of small euhedral flakes, the latter as relatively abundant and relatively coarse grains of original ?haematite, now largely altered to limonite, up to 2 mm. in diameter, typically moulded on the larger crystals of both quartz and felspar.

Occasional sedimentary xenoliths occur within this mass, consisting essentially of granular quartz, only slightly recrystallized, and of scattered biotite, which has been more thoroughly reconstituted (6807). No transfer of material from the igneous rock appears to have taken place.

### *Contact Rocks*

The contact relationships of the different masses are very similar. In each case, the plutonic phase is preceded by flows, dykes and agglomerates of trachytic rocks, into which it is intrusive and which it has contact metamorphosed. The Frenchman's Hill mass is completely surrounded by these trachytes and does not come into contact with schists or gneisses, but at Mt. Brothers and McFarlane's Lookout the syenites have intruded the low-grade schists and have altered them to blue-grey or blue-black hornfelses for distances of five to ten chains from the contact.

In the less altered rocks, recrystallization is restricted to the reconstitution of white mica into irregular aggregates of small sub-parallel flakes (6808) and the development of poorly defined spots of incipient cordierite, up to 1 mm. in diameter (6809). In rocks nearer the contact, biotite is developed as abundant small euhedral deep-brown flakes (6810), and is accompanied by large irregular patches of strongly poikilitic cordierite, developed from the spots of the lower-grade rocks (6811, 6812). These rocks may show parellelism of the newly formed biotite flakes and parallel elongation of the cordierite poikiloblasts, or of the original quartz grains, but no banding or foliation is ever apparent in the hand-specimen.

A contact between syenite and granodiorite has been described by Broadhurst and Campbell from Mt. Leinster, but none of the syenites in the area of the present investigation comes into contact with the granodiorites or their gneissic equivalents.

### *Thickness of Cover*

The question of the cover of these syenites presents an interesting problem, since they now rise to approximately 2000 ft. above the level of their associated flows and pyroclastics, as at Pyle's deposit on the west flank of Mt. Brothers. Assuming a cover of only 1000 ft.. for the Mt. Brothers mass and original relief of the order of 1000 ft., this still presupposes an original thickness of 2000 ft. for the trachyte series over an area of the order of 80 to 100 square miles. The volume of lava involved is therefore comparable to that met with in the dacite suites of central Victoria, but the available evidence does not justify any conclusions as to the mechanics of its extrusion.

### Associated Dykes

The number of dykes to be definitely correlated with the trachyte-syenite complexes is comparatively small and only a limited range of petrological types is represented.

Aplites are best represented in and near the northern and eastern parts of the Mt. Brothers mass, especially in the vicinity of the contact between the porphyritic granite and the even-grained syenite of McFarlane's Lookout. They are normal aplites, rich in quartz and perthitic orthoclase, and contain biotite as their main ferromagnesian constituent (6813).

Normal trachytic dykes are most abundant in the immediate vicinity of Omeo, where they show a general tendency to be arranged radially with respect to Frenchman's Hill. Flow structure is usually visible in the hand-specimens, as well as in thin section (6814, 6815, etc.), and is due to the local parallelism of the felspar laths of the matrix. Quartz is usually present in small amounts only, occurring as scattered interstitial grains or as pools enclosing the felspar laths of the matrix. Phenocrysts of alkali felspar are occasionally present (6818), but do not greatly affect the texture of the rock as a whole. Abundant magnetite, ranging from minute scattered needles to clusters of relatively large crystals, is always present, typically altering to limonite, which is responsible for the characteristic pink or pale brown colour of these rocks. It is occasionally accompanied by remnants of chloritized biotite (6814, 6818), which, however, always remains subordinate in amount.

One compound dyke from Wilson's Creek is exceptional in containing numerous xenoliths of sedimentary origin, mainly quartz-rich schists, up to 2 in. across. Those portions of the dyke richest in xenoliths (6819, 6820) are characterized by fine grain-size and by the abundance of relatively large brown biotite flakes, which may, however, have been derived from the xenoliths. This contrasts with the texture of the remainder of the dyke (6821), which is coarser-grained, slightly porphyritic and poor in dark minerals other than magnetite.

A dyke from the north shoulder of Mt. Livingstone is of interest in showing evidence of shearing, suggesting that movements at that locality, which falls within the Dry Creek - Three-Mile Creek shear zone, persisted rather longer than elsewhere in the area. The rock is traversed by irregularly spaced, sub-parallel shear planes, intersecting the flow-structure at a low angle, along which concentration of limonite has taken place.

In the eastern part of the area, trachytic dykes are less numerous, although Broadhurst and Campbell have recorded a variety of types from Mt. Leinster. Apart from the aplites of the Mt. Brothers mass, only two dykes associated with the alkaline complexes were found in this part. One specimen (6822), from the Main Divide, east of Marengo Gap Hill, is a quartz-rich, trachytic type with poorly developed flow structure and containing relatively abundant magnetite and biotite in various stages of alteration. The other (6823), from east of Mt. Bung Bung, is a more basic rock, not unlike some of the lamprophyres in appearance, but distinguished by the presence of sub-rectangular phenocrysts of simply twinned orthoclase, up to 1 mm. long. The original ferromagnesian minerals, both among the phenocrysts and in the matrix, have been completely replaced by chlorite-epidote aggregates, and are no longer identifiable. Before alteration, the rock may have had the mineral composition of a vogesite, but no comparable unaltered rocks have been found in the area.

### Granite Porphyries

The granite porphyries of the area occur as a number of small stocks, especially in the southern portion of Frazer's Tableland and in the hills north of Mt. Brothers, and as a few rather larger complexes, of which Mt. Sisters, Mt. Pleasant, Mt. Bung Bung and Marengo Gap Hill are the most important. The total extent of these rocks within the area is of the order of 30 square miles, but very much larger occurrences are known from adjacent districts and will be referred to subsequently.

The stocks of Frazer's Tableland have been recorded by Stirling (1887e) and the complexes of the Mt. Sisters-Mt. Pleasant area by H. S. Whitelaw (1898). In addition, Broadhurst and Campbell (1932) mapped the Marengo Gap Hill occurrence in detail and showed it to be younger than the granodiorites of the gneissic series.

The rocks vary widely in texture, but maintain a relatively constant mineral association, variations within any one complex being comparable to those between representative rocks from different complexes.

At Mt. Sisters, the dominant type is a quartz-felspar porphyry containing sub-rectangular crystals of perthitic orthoclase, which tend to be grouped into small clots of eight or ten individuals, and embayed and rounded crystals of quartz, both up to 3 mm. in diameter, in a matrix composed essentially of the same minerals in micrographic intergrowth. Both constituents of these intergrowths tend to be in optical continuity with nearby phenocrysts, but the oultines of the latter are always sharply defined, showing that their crystallization was complete before that of the matrix began. Ferromagnesian minerals are represented by scattered small flakes of biotite, typically in an advanced stage of chloritization, and in one specimen (6827) by clots of small euhedral biotites and magnetites which may represent xenolithic material in various stages of assimilation. Fluorite is an important accessory in one rock (6828), where it forms scattered grains, ·3 to ·4 mm. in diameter, which have crystallized after felspar but before quartz.

A minor but very widely distributed type shows many of the features characteristic of some of the syenites, and may be regarded as transitional between the typical rocks of the two series. One specimen (6830) consists largely of irregular to sub-rectangular crystals of strongly perthitic untwinned alkali felspar (orthoclase ?), up to 2 mm. long, the enclosed member being acid oligoclase, $Ab_{85}$. The matrix is subordinate in amount and consists of smaller crystals of the same mineral, enclosed in irregular grains and small pools of quartz. Both biotite and amphibole are present, the former usually strongly chloritized, the latter pleochroic greenish brown to pale yellowish green, or deep bluish green to pale yellowish green (riebeckite ?). Another member of the same group (6831) shows again the very high contents of perthitic alkali felspar, characterized this time by a very pronounced arrangement of the inclusions in parallel or sub-parallel laminae. It differs, however, in the almost complete lack of dark minerals, and in the texture. Both quartz and felspar show a continuous gradation from micro-phenocrysts of about 1 mm. diameter down to the matrix of average grain-size ·1 mm. approximately. No graphic intergrowths are present, and the quartz occurs throughout as rounded, equidimensional granules, although adjacent grains may occasionally be in optical continuity. The felspar, on the other hand, tends to be poikilitic towards quartz, and commonly encloses blebs and granules of the latter, either throughout the crystals or in the marginal portions only.

A chilled border phase, about two to three chains wide, can be recognized along the northern edge of the mass, and is distinguished in the hand-specimen by its darker colour and finer grain-size (6832). Essentially, it differs from the main mass by the absence of quartz phenocrysts and the absence of graphic intergrowths in the matrix. The dominant ferromagnesian mineral is a deep-green hornblende with an extinction angle of 18°, occurring as abundant small prisms and irregular crystals, magnetite being subordinate, and biotite absent altogether.

Rocks from the Mt. Pleasant and Mt. Bung Bung complexes are essentially similar, ranging from true granite porphyries to transition phases between these and the syenites. Quartz may be abundant, especially in the former type, and the phenocrysts then show the bi-pyramidal habit characteristic of these rocks from all occurrences (6833, etc.).

Rocks from the Marengo Gap Hill occurrence show considerable variation, and contain representatives of most of the types already described. The dominant phases at this locality, however, tend to be more sodic in their affinities, a considerable proportion of acid plagioclase being always present. Strongly porphyritic rocks predominate, especially in the northern portion of the complex, and contain phenocrysts of somewhat embayed quartz, sub-rectangular perthitic orthoclase, and subhedral oligoclase, $Ab_{85}$, all up to 5 mm. in diameter, in a finely granular quartz-felspar matrix. Plagioclase may be subordinate to orthoclase among the phenocrysts (6825, 6826), or may almost equal it in amount, but since the ground-mass felspar is dominantly orthoclase, the rocks still fall into the group of granite porphyries. Green-brown biotite in various stages of chloritization is the dominant ferromagnesian mineral, with magnetite subordinate. Fluorite again occurs as an accessory in some specimens.

For the less obviously porphyritic types, in which plagioclase is typically present in small amounts only, a specimen from the southern portion of the mass may be regarded as typical (6834). These are in every way comparable to the corresponding rocks from Mt. Sisters, etc., and require no detailed description.

The relatively small masses of Frazer's Tableland and the Mitta Mitta valley in the vicinity of Four-Mile Creek and Eight-Mile Creek are closely comparable with some of the rocks previously described, but each mass is homogeneous, consisting of one type only. The occurrence at Gresson's Knob, about six miles north-north-west of Benambra, is typical of the group. The outcrop occupies an area of about half a mile by half a mile, and consists of a markedly porphyritic rock, containing phenocrysts of originally bi-pyramidal clear quartz, now rounded and embayed, and of pink or flesh-coloured subhedral albite, $Ab_{95}$, both up to 5 mm. in diameter. Strongly sericitized alkali felspar and bleached or chloritized biotite form smaller and less numerous phenocrysts, while the pale yellow matrix consists essentially of finely granular quartz and unidentified felspar (6837).

The masses of Sloan's Knob, east of Morass Creek, consist of petrologically similar types, but their field relations are masked by flows of Newer Basalt, which overlie them to the west, and their eastward extent was not investigated. Similar masses also outcrop in the Mitta Mitta valley, opposite the mouth of Four-Mile Creek, with the addition of a less acid type with a coarser-grained matrix. In this rock, biotite as well as quartz and felspar forms phenocrysts, and a gradation exists between these and the crystals of the matrix.

### Field Relationships

The relationships of the various types within any one complex to one another are not readily discernible. At Mt. Sisters there is a suggestion that the more porphyritic and more quartz-rich phases transgress the boundaries of the more nearly equigranular and more felspathic types, and are therefore younger than these. No actual contacts, however, were exposed. At Mt. Bung Bung and Marengo Gap Hill the various phases alternate irregularly and do not appear to be connected by transition types, but again no actual contacts were seen.

The intrusive nature of the Mt. Sisters mass is evident from the contact metamorphism which the low-grade schists, and also the Tambo Formation as already described, have undergone at its boundaries. Similar alteration on a smaller scale can be detected also at the borders of the other, smaller masses. Even at Mt. Sisters, high-grade metamorphism is restricted to a zone within a chain of the contact, but the effects are very well shown by some inliers of sedimentary rocks in the vicinity of the low saddle between Mt. Pleasant and the Main Divide. The products here are relatively fine-grained blue-black hornfelses, containing abundant small biotites in random orientation, and occasional spots of incipient cordierite, poikiloblastic towards both quartz and biotite (6835).

A small occurrence of granite porphyry at Mt. Little Tambo is important because it gives an indication of the relationship between the granite porphyries and the trachyte-syenite complexes. The rock is pale grey, markedly porphyritic, and rather finer-grained than most members of this group, occurring as an isolated outcrop of two to three chains diameter, completely surrounded by trachytic rocks. The exact boundaries of this occurrence are masked by hillwash and vegetation, but appearances strongly suggest that it is intrusive into the trachytes. If it is regarded as contemporaneous with the larger masses such as Mt. Sisters, and there is no reason why this should not be done, these masses are likewise post-trachytic.

### Alteration

Hydrothermal alteration of these masses is not uncommon, and can be best observed at the south-west extremity of the Marengo Gap Hill occurrence and in the eastern part of the outcrop at Gresson's Knob. In the hand-specimen the altered rocks rather resemble leached outcrops, but no sulphides are present and the alteration can be seen to consist essentially of the replacement of original felspar by relatively coarse aggregates of white mica, and of original biotite by white mica and chlorite (6838, 6839), together with a certain amount of silicification. The altered portions pass into the main unaltered masses within a relatively short distance and the changes must be ascribed to the action of vapours or solutions derived from the intrusions themselves. There is a close analogy between these processes and those which caused the alteration of some of the dyke rocks associated with the Red Granite, to be described later.

## Red Granite

The Red Granite is the largest single intrusion in the area, occupying an area of approximately twelve miles by six miles, between Glen Wills and Hinnomunjie Bridge, with its maximum diameter N.E.-S.W., approximately at right angles to the trend of the country rock structures. It is well exposed over most of this area and typically develops numerous large tors.

It occupies the central portion of the area enclosed by the great southerly bend of the Mitta Mitta, but does not appear to have had a major effect on the development of the topography. The Big River, Bundarra River and Cobungra River all cut across its contact near the Blue Duck Hotel, as does the Mitta Mitta near the mouth of Nine-Mile Creek, and in no case except that of the Bundarra is there any noticeable change in the valley cross-section. The steepening of the Bundarra valley, however, is due to rejuvenation by the Livingstone Fault, and the coincidence of the knick point with the granite boundary is purely coincidental.

The mass is comparable to the Red Granites of Pine Mt. and Mt. Mittamatite described by Edwards and Easton (1937), differing only in its somewhat greater extent and in the presence within it, especially near the southern and south-eastern borders, of very numerous veins, dykes and lenticles of aplite, pegmatite and quartz porphyry. Of these dyke rocks, only the quartz porphyries extend into the country rock for any considerable distance and no attempt has been made to map the very numerous smaller masses, which locally equal the main mass in abundance over areas up to half a mile across. A smaller number of intermediate and basic dykes are also associated with the mass, and occasionally cut it. They will be discussed in detail in a later section.

### Petrology

The mass itself is reasonably homogeneous, the typical rock (6733, 6735) consisting essentially of quartz and perthitic orthoclase in about equal amounts, occasionally tending to form a very coarse type of micrographic intergrowth, together with slightly less abundant oligoclase, $Ab_{70}$. Rarer biotite, pleochroic yellow to deep brownish green, occasionally bleached, and scattered magnetite are the only other constituents present in significant amount. The rock is approximately equigranular, with an average grain-size varying between 1 and 3 mm., but may appear porphyritic in the hand-specimen, due to the tendency of the plagioclase to occur as euhedral crystals, which contrast with the irregular outlines of the other major constituents. The red colour is apparently due to the presence of finely divided haematite in the alkali felspar.

### Contact Phenomena

The contacts of the main mass are not usually well exposed. Where the country rocks were previously unmetamorphosed sediments, contact metamorphism has been restricted to the formation of cordierite-biotite hornfelses for a few chains from the contact, and where the rocks had previously undergone regional metamorphism the original schistosity and spotting are only partly obliterated.

Where the Red Granite is intrusive into gneisses, as on the west slopes of the Knocker and near the mouth of Nine-Mile Creek, sharp contacts do not occur. The general trend of the boundaries cuts across the foliation of the country rock, but a transition zone, from one to ten chains wide, appears to connect the two rock types. This is illustrated by a series of specimens across the contact on the western slopes of the Knocker (6736-6743). The first specimens (6736, 6742, 6743) show what is essentially a contact-metamorphosed ortho-gneiss. Anhedral quartz, perthitic orthoclase and subordinate oligoclase, $Ab_{75}$, all with an average grain-size of about 2 mm., together with less abundant, smaller flakes of biotite, made up the major portion of the original rock. Along the grain boundaries, and within some of the larger grains, especially of alkali felspar and of biotite, granulation and recrystallization have given rise to fine-grained aggregates of quartz, alkali felspar and biotite, the latter locally showing good parallelism, together with topaz, clinozoisite, muscovite and bright yellow isotropic pinite(?) in smaller amounts. The second group of specimens (6737, 6741) approximate to the normal granite, differing mainly by their paler colour, the hand-specimens being cream rather than reddish, and by their distinctly higher contents of biotite. In thin section, they show the coarse micrographic intergrowth and the deep green biotite characteristic of the Red Granite, with a strong suggestion that, in some instances at least, the orthoclase has developed at the expense of quartz. The proportion of oligoclase, $Ab_{80}$, is somewhat higher than in the main mass of the Red Granite and the rock may be regarded as a contaminated phase of the latter, or as the equivalent of a chilled border phase, slightly more basic than the main mass. The third group of specimens (6738, 6739, 6740) appear scarcely distinguishable from the typical Red Granite in the hand-specimen, but still contain significantly higher proportions of plagioclase and biotite than the normal rock. No specimens illustrating the actual transfer of material from the granite to the country rock were obtained, but the absence of a sharp contact strongly suggests that such a process must have taken place at least on a small scale.

## Associated Dykes

In the case of the Pine Mt. and Mt. Mittamatite occurrences, the associated dyke swarms preceded the main intrusion (Edwards and Easton 1937), but the relationship is reversed in this area, since some at least of the hypabyssal rocks cut the main intrusion. These include a large number of small veins and lenticles of aplite and pegmatite, which show a marked tendency to be concentrated in a comparatively narrow belt, parallel to the boundary of the granite mass, and a smaller number of more persistent dykes of quartz felspar porphyry which extend for distances of up to six or eight miles into the country rock, especially to the south and south-east of the main mass.

### *Aplites and Pegmatites*

A specimen from the Alpine Highway (6744) may be regarded as typical of the aplitic rocks, with orthoclase present in about equal amount to albite, $Ab_{90}$, and muscovite as the only ferromagnesian mineral. In a related rock from the Glen Wills Highway (6745), the orthoclase is strongly perthitic and locally passes into oligoclase-antiperthite, $Ab_{85}$. With an increase in the ferromagnesian constituents, mainly chloritized biotite, these rocks pass into a type which might be described as a plagioclase aplite, characterized by the presence of strongly zoned, untwinned plagioclase side by side with albite, similar to the above, and represented by rocks from the Glen Wills Highway and other localities (6746, etc.).

A somewhat larger intrusion of this type which deserves mention on account of some structural peculiarities occurs on the south-eastern slopes of Mountain Creek. This is a relatively coarse-grained aplite which forms a lenticular mass of about 300 yards by 150 yards and consists essentially of quartz, albite, $Ab_{95}$, slightly perthitic orthoclase and abundant muscovite, which occurs as small ragged flakes arranged in two sets of planes intersecting at 60° to 80° (6747). Scattered through the mass and aligned normal to the lineation resulting from the intersection of these two sets of planes, are abundant small veins and lenticular masses of pegmatite, consisting of irregular quartz, subhedral pink orthoclase, muscovite and tourmaline, all as individuals up to 2 cm. in diameter. The muscovite of these pegmatites is arranged predominantly normal to the walls of the veins, which grade into the matrix in a distance of about 1 to 2 cm. Using Sander's nomenclature, these veins are regarded as occupying tension gashes lying in the *ac*-plane of deformation of the rock, while the two sets of planes outlined by the muscovite flakes are thought to represent shear planes coinciding with (*h0l*) directions. Moreover, the absence of deformation within individual grains indicates that the movements responsible for these structures occurred during a late stage of crystallization rather than after complete solidification.

Another rock from Bingo Creek is closely comparable to the above, but lacks the directional structures (6748). It differs from the majority of the members of this group by its rather coarser grain-size, 1 mm. being the average for most of the major constituents, which are quartz, slightly cloudy orthoclase and acid oligoclase, $Ab_{85}$, together with relatively abundant muscovite. The felspars are typically subhedral, the quartz anhedral or interstitial, with adjacent individuals occasionally coarsely intergrown, and the muscovite occurs as relatively coarse flakes, typically moulded on the felspars and occasionally coarsely intergrown with quartz.

In addition, a very distinctive group of rocks, which may be referred to as aplites or fine-grained pegmatites, occur as numerous irregular masses within the main area occupied by the Red Granite. The extent of these rocks varies from veinlets and lenticles a few feet long to masses a quarter of a mile or more in diameter, the majority occurring in the south and south-eastern portions of the mass. A typical specimen (6734) is a medium-grained even-grained granular whitish rock, consisting of embayed, originally euhedral quartz, and subhedral albite, $Ab_{95}$, together with less numerous but rather larger crystals of ?microcline, which occasionally shows evidence of having developed at the expense of quartz. Original biotite is represented by occasional fine-grained chlorite-sericite aggregates, and magnetite occurs as scattered small crystals. The boundaries of these masses are usually sharp but irregular and the rocks are thought to be the products of a residual phase of the Red Granite magma, relatively enriched in soda and in volatile constituents, the latter being responsible for the slight auto-pneumatolytic alteration which most of these rocks show.

### *Felspar Porphyries and Porphyrites*

Of the felspar porphyries and porphyrites, only those occurrences which have been definitely correlated with the main Red Granite intrusion will be discussed in this section. These include especially a group of dykes from Bingo Creek, Sam's Hill and McMillan's Lookout, averaging 12 ft. to 15 ft. in width and striking dominantly N.W.-S.E., parallel to the dominant trend of the country rocks.

In the hand-specimen, they are pink or flesh-coloured rocks, studded with phenocrysts of glassy bi-pyramidal quartz, cream and red felspar and occasional greenish-black, strongly chloritized biotite and/or hornblende. The size of the phenocrysts in any one rock is approximately uniform, 1 to 2 mm. being usual (6749, 6750), but 5 to 10 mm. being occasionally found (6751). In thin section, the quartz is seen to be strongly embayed and the dominant felspar is albite, $Ab_{95}$, showing albite and pericline twinning and tending to occur in small clots of six to ten individuals. Slightly perthitic orthoclase is subordinate, but always present. The matrix consists essentially of quartz and an unidentified felspar, probably orthoclase, the latter locally in micrographic intergrowth with quartz or recrystallized to form spherulitic aggregates. The original ferromagnesian minerals have been almost completely replaced by chloritic aggregates and appear to have originally included both hornblende and biotite. Muscovite is typically absent, but iron ores are present in moderate amount.

Slight shearing has affected some of these rocks (6752, 6753), resulting in traces of granulation along irregularly spaced planes and causing the rocks to break more readily in certain directions.

### *Contaminated Felspar Porphyries and Porphyrites*

Two rocks from the Glen Wills Highway near the Bingo saddle (6754), and from the lower portion of Day's Creek (6755, 6756), deserve special attention. They are quartz-felspar porphyrites comparable with the above types, except for the texture of the matrix, which tends to be controlled by the presence of abundant uniformly small laths of unidentified felspar, quartz being less abundant and typically interstitial. The proportion of chlorite is relatively high and epidote is also present as isolated grains, as small aggregates and as rims around some of the rounded and embayed quartz phenocrysts. The most distinctive feature of these rocks, however, is the presence within them of numerous sharply defined patches, up to 2 in. in diameter, which differ from the main mass of the rocks in their higher contents of chlorite and epidote and by the absence or relative scarcity of phenocrysts. These patches, which are very prominent in the hand-specimen because of the contrast between their greenish colour and the light brown or reddish tint of the matrix, appear to be xenoliths of a more basic rock, possibly comparable with the hornblende porphyrites described in a later section. No actual contacts between the two rock types were observed, but if the more basic rocks belong to the same general period of igneous activity, as seems very probable, then the order is the reverse of that observed by Edwards and Easton in north-eastern Benambra, where the succession is from acid to basic types.

### Granitic Rocks of Uncertain Age

Two rather inhomogeneous masses of granitic rocks are possibly to be correlated with the Red Granites. One occurs in the Big River valley about five miles upstream of Glen Wills. It consists of a complex of granite, granite aplite and granite porphyry (6757, 6759), all characterized by the presence of perthitic orthoclase, which forms the phenocrysts of the porphyritic types and is approximately equal in amount to plagioclase in the even-grained rocks.

The other occurrence, from the Mitta Mitta valley, comprises fine-grained granites and granite aplites which have intruded slates and sandstones of the Middle Devonian (?) Wombat Creek series. A typical specimen (6760) consists of subhedral perthitic orthoclase and subordinate oligoclase, $Ab_{70}$, both up to 1 mm. in diameter, together with aggregates of recrystallized quartz and occasional biotite flakes. Some contamination is indicated by the presence of occasional irregular aggregates of bright orange pinite, representing altered cordierite grains.

The recrystallization which these rocks have undergone tends to suggest their possible correlation with the gneisses and associated granodiorites, but their mineral assemblages are more closely related to those of typical younger intrusions, such as the Red Granite itself. Correlation with these younger intrusives is further supported by the fact that they are younger than the Wombat Creek beds, probably Middle Devonian, whereas the typical gneisses and granodiorites elsewhere in eastern Victoria are pre-Middle Devonian.

## MISCELLANEOUS DYKES

There are great numbers of dykes not directly associated with any of the major intrusives. They include porphyries and porphyrites, diorites, lamprophyres, dolerites and other basic rocks. There is evidence connecting the more acid dykes with the Red Granites. Again, there is a suggestion of a gradation from these rocks through diorites and lamprophyres to the basic rocks, and therefore of a connection between all these dyke rocks and the Red Granites.

### PORPHYRIES AND PORPHYRITES

These rocks are very abundantly represented in the valleys of Bingo Creek and of Livingstone Creek and its major tributaries, and also occur in the northward extension of this belt as far as Frazer's Tableland, the Knocker and the Wombat Creek valley. In the remainder of the area, however, they are rare or absent. This distribution is one of the indications for a genetic relationship to the Red Granite, which occupies a central position within this belt, and agrees with the observations of Edwards and Easton, who describe a similar group of rocks as co-magmatic with the Red Granites of Pine Mountain and Mt. Mittamatite. In the latter areas, however, the intrusion of the dykes preceded that of the main batholiths, while in this area the relationships appear to be reversed. Several of these dykes actually cut the Ren Granite (6841, etc.), and others are closely associated with aplites and pegmatites undoubtedly derived from this mass.

Generally speaking, the rocks may be referred to as quartz porphyries and porphyrites, grading into felspar porphyries and porphyrites. If quartz occurs as phenocrysts, it is typically rounded and embayed, euhedral crystals being only occasionally found (6842). Phenocrysts of felspar tend to occur in small clusters and are commonly subhedral. Either orthoclase or plagioclase may predominate, the latter ranging from acid oligoclase, $Ab_{85}$ (6841), to albite, $Ab_{95}$ (6843, 6844). The grain-size of the phenocrysts is always roughly uniform in any one rock, but varies from rock to rock, 2 mm. being about the maximum observed. Phenocrysts of biotite are less common, and are typically strongly chloritized or replaced by aggregates of epidote (6845, 6846). The matrix is invariably fine-grained, consisting of quartz, felspar and biotite in varying proportions.

In the hand-specimen, the rocks are frequently seen to be faintly banded, due to slight variations in grain-size or mineral composition of the matrix, but the texture is invariably granular, and no flow structures are visible in the thin sections. A very common feature is the recrystallization of the matrix, with the development of spherulitic aggregates of secondary felspar, the original phenocrysts of quartz or felspar frequently acting as nuclei for these aggregates. In one specimen (6851), leucoxene is an important constituent of the matrix, forming pseudomorphs after ilmenite. Quartz veins, up to ·5 mm. wide, cut across some of these rocks and may be arranged randomly or in well defined parallel sets (6852, etc.).

If quartz phenocrysts are absent, plagioclase usually predominates over orthoclase, although there are a few exceptions (6853, 6854). The phenocrysts are typically albite, $Ab_{95}$ (6855, 6856), sometimes attaining the composition of pure albite (6858). Banding is still occasionally present (6859), due mainly to variations in the amount of quartz present in the matrix.

Some rocks have a greater proportion of dark minerals and form a link with the more basic types, in which hornblende is an important constituent. Unfortunately they are frequently much altered, the original ferromagnesian minerals being replaced by chloritic aggregates, so that the presence or absence of hornblende in the original rock is often difficult to decide (6860, 6861). At the same time epidote is developed and many of the original felspar phenocrysts are replaced by finely granular aggregates of zoisite.

The appearance of the hand-specimens of these rocks varies markedly with the degree of alteration. The least altered rocks are grey or greyish green, the pink felspar phenocrysts and deep green crystals of the ferromagnesian minerals being sharply defined from the matrix. With more advanced alteration, however, the rocks as a whole assume a speckled appearance, ranging from reddish brown to dull green, and the original phenocrysts are no longer clearly distinguishable.

## Basic Dykes

With increasing amounts of ferromagnesian minerals and the loss of marked porphyritic texture, the porphyries and porphyrites appear to pass into diorites, lamprophyres and other basic rocks which comprise perhaps a quarter of all dykes of any kind in the area. They occur as dykes and small lenticular masses up to about two chains by ten, as in the lower part of Bingo Creek and near the head of the Bundarra River, but many of the occurrences are very much smaller, dykes only one or two feet thick being the most common, particularly among the more basic types.

Their distribution corresponds reasonably closely to the margins of the main gneissic masses of the metamorphic complex. With very few exceptions, they occur within two well defined areas. Of these, one occupies a belt about eight miles wide, parallel to the main schist-gneiss contact, extending in an approximately north-north-easterly direction from Omeo to Mt. Bogong. The other comprises the lower portion of the Rocky Valley and Pretty Valley branches of the East Kiewa River, especially near the Junction Dam, and may represent the most easterly portion of a similar belt on the west flank of the main gneissic belt.

### *Hornblende Diorites and Lamprophyres*

Specimens in which hornblende was originally present in significant amounts have about the same distribution as the types discussed earlier, and in addition form important masses in two dyke-complexes, situated on the north shoulder of Mt. Livingstone and on the One-Mile Creek - Four-Mile Creek saddle of the old Wombat Creek track respectively. These complexes occupy areas of about one mile by half a mile and four miles by one mile respectively, within which only igneous rocks outcrop. The rocks, however, show great variation in composition and texture, ranging from quartz felspar porphyrites, through felspar porphyrites, to diorites, etc. Exposures are insufficient to show the relationships between the various types, and no attempt has been made to map them in detail. The size of the individual masses within the complexes ranges from a few chains to about half a mile in diameter, and the relative abundance of the various types varies from place to place.

The typical diorites are medium-grained, even-grained rocks, composed essentially of hornblende and intermediate plagioclase, with smaller amounts of iron ores, quartz and alteration products of the chlorite and epidote groups. In the hand-specimen, they have a characteristic speckled white and green appearance, with an average grain-size of between 1 and 2 mm. for most members of the group. The only exception is a rock from Bingo Creek (6872), which shows a markedly inequigranular texture with abundant micro-phenocrysts of hornblende set in a fine-grained matrix of stumpy plagioclase laths and rare interstitial quartz.

The hornblende occurs always as subhedral prismatic crystals, locally chloritized, occasionally moulded on felspar or enclosing small crystals of the same. It is typically pleochroic dark brown to pale brown, or less commonly dark bluish green to pale greenish brown, with a maximum extinction angle of 18° to 20°. In one rock (6876) zoning occurs, cores of the bluish green variety being surrounded by rims of the brownish green type. Biotite is never abundant, and if present is chloritized to about the same extent as the hornblende. Epidote is commonly present and becomes important in some rocks. Iron ores are always present, usually as scattered relatively large crystals, occasionally showing alteration to leucoxene, indicating ilmenite or titaniferous magnetite.

The plagioclase in most members of the group varies between andesine, $Ab_{60}$, and acid labradorite, $Ab_{50}$, and is typically strongly zoned. Very commonly, a clear rim is sharply set off from a strongly sericitized core, so that the change in composition cannot usually be estimated. Orthoclase is only rarely present, and is never abundant, forming relatively large, irregular grains, within which any of the other minerals of the rock may be enclosed. Quartz, varying from a major constituent to a mere trace, has a very similar mode of occurrence, and is never completely absent. In some of the more altered rocks, however, it is possible that some at least of the quartz may have been introduced subsequent to the crystallization of the rock. Some rocks of this group again contain albite, $Ab_{90}$ to $Ab_{95}$, but do not appear to differ from the remaining members in any other way (6873, 6874).

The fine, even-grained rocks have no exact equivalents to the diorites, but some of the more ferromagnesian-rich porphyritic types approximate fairly closely to them in mineral composition. These include a number of rocks outcropping within or just outside the main mass of the Red Granite (6871, 6881, 6882, etc.). In these rocks, quartz is still occasionally present as small rounded phenocrysts, but more commonly it is restricted to scattered interstitial grains. Basic andesine, $Ab_{50}$ to $Ab_{60}$, is characteristic of the phenocrysts (6865, 6866, etc.), but the relation of this group to the previous one is shown by the fact that albite, $Ab_{95}$, still occurs in some of these rocks (6862, 6870), which again show no other points of difference from the remainder of the group. Both these felspars occur as subhedral crystals up to 2mm. long, and occasionally, as in the rocks from the One-Mile Creek - Four-Mile Creek complex, the former show faint oscillatory zoning. In the more altered rocks, these felspars are completely sericitized and occasionally are crowded with minute granules of a colourless mineral of the zoisite group. The groundmass felspar is not usually determinable, occurring as squat subhedral laths of approximately uniform size within any one rock, but varying somewhat from specimen to specimen.

If both biotite and hornblende were originally present, the latter is invariably the less altered of the two. It forms abundant subhedral prismatic crystals in the matrix of all these rocks and occasionally also appears as phenocrysts (6866, 6868). The pleochroism is typically light to dark brown, but changes to greenish tints as chloritization progresses, the phenocrysts being typically affected before the smaller crystals. Biotite appears to have been restricted to the phenocrysts and is now only indentifiable by the preservation of the outline of the original flakes, having been completely replaced by fine-grained aggregates of chlorite and of a pale-brown non-pleochroic mica. Magnetite is an important constituent in one rock (6870), and pyrite has been introduced in significant amounts into another (6871).

### *Augite Diorites and Lamprophyres*

With the appearance of pyroxenes in the hornblende diorites and lamprophyres, transition to the next group begins. These are the quartz-hornblende-augite diorites of Edwards and Easton, and the augite lamprophyres of Baker. They are characterized by the presence of variable amounts of augite as subhedral micro-phenocrysts, or irregular interstitial grains, or both. The pyroxene is always of a diopsidic type with $2\,V = 50°$ or higher, and correspondingly high extinction angles of 40° to 45°. Occasional purplish tints are suggestive of slight enrichment in titanium (6886). A tendency to glomero-porphyritic texture is noticable in a rock from Day's Creek (6887), with the segregation of subhedral augites of about 1 mm. diameter into clots of six to eight individuals, occasionally in association with less numerous felspars of about the same size. Hornblende is always present, but may be subordinate to the pyroxene in amount. It does not differ essentially from that of the rock types previously described, and very occasionally shows mantling of the pyroxene. Typically, a gradation in size from the micro-phenocrysts to the matrix is shown by both augite and hornblende. In some rocks, however, the augite may be restricted to the micro-phenocrysts, and hornblende is the only ferromagnesian in the matrix (6885, 6889).

The groundmass felspar of these rocks occurs invariably as somewhat ragged laths, which maintain a reasonably uniform grain-size within any one specimen, but which are always sericitized beyond possibility of identification. In the same way, the micro-phenocrysts of felspar, up to 2 mm. in diameter, which were originally present in some of the rocks, have been completely altered to sericite-calcite-zoisite aggregates, and are no longer identifiable. Quartz, as in the last group of rocks, is present only as rare interstitial grains or as xenocrysts surrounded by reaction rims of epidote. Iron ores are also present in significant amounts, although usually as very small crystals.

A closely allied type is represented by non-porphyritic rocks of similar mineral composition, but with a texture dominated by the felspars (6890-6892). These felspars occur as subhedral to ragged unzoned laths, varying from about ·2 mm. to 1 mm. in length within any one specimen, and are again very sodic in composition, albite, $Ab_{90}$ to $Ab_{95}$, being typical. Augite occurs either as prismatic subhedral crystals, idiomorphic against felspar, or as less regular interstitial and ophitic grains. In either case, hornblende is subordinate, magnetite relatively abundant and quartz present in very small amount as minute interstitial grains only.

### *Dolerites*

With an increase in the amount of pyroxene and a slight change in the composition of the plagioclase, these rocks pass into the typical dolerites, best represented in this area by a series of rocks from the immediate vicinity of Omeo, especially Day's Creek and Bingo Creek. They are dark grey-green in the hand-specimen, becoming lighter on weathering. and, because of the marked ophitic texture, tend to appear finer-grained than they actually are. The pyroxene is typically a purplish, non-pleochroic, titaniferous augite with moderate 2V, 55° to 60°, and high extinction angles, 35° to 45°. Strongly ophitic grains of irregular outline are present in every specimen (6893, 6894), but occasionally a few idiomorphic crystals also occur (6895). Some of these specimens (especially 6895) show intimate intergrowths of two pyroxenes within the outlines of one subhedral crystal, the product being not unlike a coarse perthitic intergrowth in appearance.

The satisfactory determination of both members of any given pair was not possible in any of these specimens, but at least one member of each pair appears to be the normal augite of these rocks, and no orthorhombic pyroxenes appear to be involved. Hornblende is never preserved as such, but may be represented by some of the numerous chloritic aggregates which are always present. Iron ores are present in relatively small amount and have occasionally been partially replaced by leucoxene (6893). The felspars may attain a maximum length of about 2 mm., and are rather more basic in composition, labradorite, $Ab_{45}$ to $Ab_{40}$, being typical. Quartz and alkali felspar are absent or very rare, except for a few rocks rich in albite, $Ab_{95}$ (6895, etc.).

Alteration differs from that of the earlier described rocks in that calcite tends to be developed instead of epidote. One rock from Bingo Creek (6896), into which pyrite has been introduced in relatively large amount, shows a development of numerous almost spherical aggregates of a chloritic mineral, up to 1 mm. across, each surrounding a single crystal of calcite. These aggregates cut across the original textures of the rock and appear to have resulted from the indiscriminate local replacement of all the original minerals.

### *Basic Lamprophyres*

A small group of rocks from the same localities may be referred to as basic augite lamprophyres, bearing the same relationship to the dolerites as the hornblende lamprophyres do to the diorites. They are characterized by a panidomorphic texture and by a continuous gradation in the size of all the major constituents. The felspar shows a slight gradation from labradorite, $Ab_{40}$, in the larger crystals to acid labradorite, $Ab_{50}$, in the smaller ones, although zoning is typically absent. Alteration, with the development of chlorite flakes and epidote granules, arranged along the cleavages of some of the larger crystals, is not uncommon in some rocks (6897, 6898), while sericitization is the dominant process in others (6899).

The pyroxenes rarely exceed ·5 mm. in diameter, and are similar to those of the dolerites. Hornblende is represented only by rare small needles, but may have been largely replaced to form some of the chloritic aggregates which are abundant in all rocks of this group. Others show evidence of having been derived from pyroxenes, preserving the outline of the original crystals, including a number which attain a diameter of about 3 mm. Magnetite is abundant as relatively large crystals and skeleton crystals. Quartz is present only as rare interstitial grains and as occasional xenocrysts, the latter showing reaction rims, composed of numerous minute augite and/or epidote needles growing radially inwards from the margin.

### *Basaltic Dykes and Monchiquites*

The basaltic dykes of the area are represented by rocks from Day's Creek (6900, 6901), Livingstone Creek (6902), and the Mt. Wills-Mt. Bogong ridge (6903). In the hand-specimen, they appear blue-black, very dense and only slightly porphyritic, but in thin section they show a markedly porphyritic texture, phenocrysts of labradorite, $Ab_{40}$, or of diopsidic augite with minor felspar, being embedded in a uniformly fine-grained matrix of plagioclase laths, augite granules and iron ores. Extensive alteration of the felspars to sericitic aggregates and of the pyroxenes to chlorite-calcite aggregates is typical. Olivine is absent, but quartz may occur as rare interstitial grains.

A single occurrence within the area, represented by a dyke from the workings of the Maude and Yellow Girl Mine, Glen Wills, has been referred to as a monchiquite (Edwards 1938). It differs from the basaltic dykes mainly in the presence of abundant small sub-rectangular biotite flakes in the matrix, in addition to the usual plagioclase, augite and iron ores. A few felspars were originally present as phenocrysts, but these have been completely replaced by fine-grained aggregates of calcite and are no longer identifiable (6904).

## The Eruptive Sequence of Alkali Rocks and Dykes

The Trachytes, Syenites, Granite Porphyries and Red Granite appear to belong to one general eruptive cycle. Close association in the field and similarity of mineral composition show that the Syenites and Trachytes are products of the same magmas, the intrusive phase following the extrusive. Transitional types between the Syenites and Granite Porphyries indicate a close relationship between these two groups and the separation of them is really somewhat arbitrary. At Mt. Little Tambo it is reasonably certain that granite porphyry has intruded trachyte, and it also appears that for the area as a whole syenite preceded granite porphyry, although Broadhurst and Campbell (1932) tentatively suggested that porphyry preceded trachyte and syenite in the Mt. Leinster complex. The Red Granite of the Knocker does not come in contact with any of these rocks and its relation to them is deduced on more indirect evidence. The Granite Porphyries intrude the Tambo Formation of probably late Middle Devonian age, which therefore is the lowest possible age for the alkali rocks.

The nearest known comparable occurrence of syenitic rocks is the Mt. Dromedary complex in southern New South Wales, described by Ida Brown (1930) as consisting of banatite (quartz monzonite), monzonite, and minor amounts of shonkinite, essexite, jacupirangite and ijolite. It is intrusive only into Lower Palaeozoic strata but is thought to be of Permo-Carboniferous age because of petrological similarities with lavas of that age occurring in the same general region. There is, however, no compelling evidence in favour of correlating the Mt. Dromedary rocks with those of eastern Victoria.

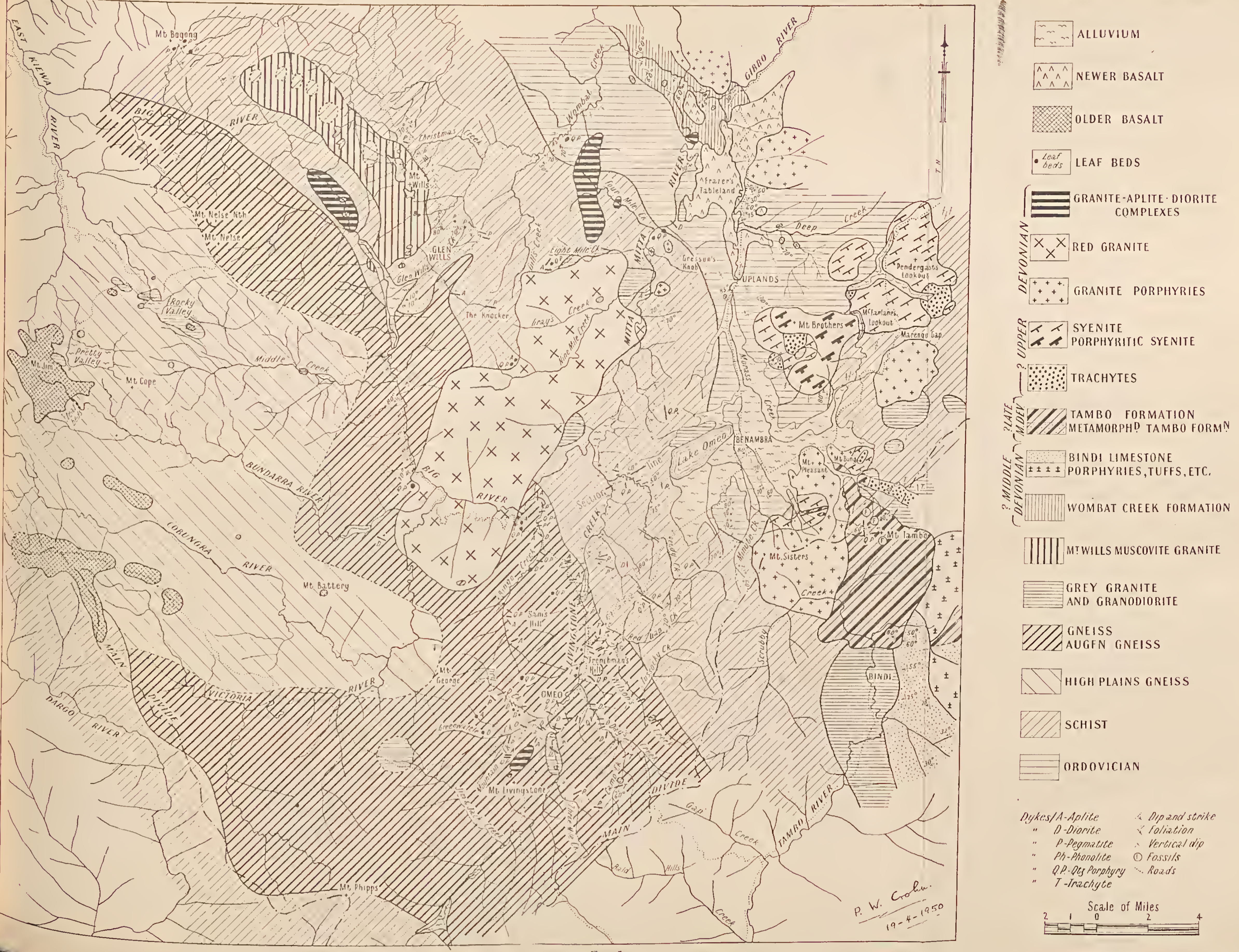
Other workers have suggested a Tertiary age for the Syenites and Trachytes, e.g., Edwards (1939), on the grounds of petrological analogy between them and the alkali rocks of central Victoria which are differentiates of Tertiary basaltic magmas. However, a correlation with the Newer Basalts is out of the question. Flows of Newer Basalt occur in the Morass Creek and Mitta Mitta valleys only about three miles from the western boundary of the Mt. Brothers complex, and their youth has been demonstrated by Hills (1939), who showed that the swamps of Uplands, six miles north of Benambra, caused by the flows blocking the valleys, are only now being drained by the cutting of a new channel through the basalt barrier. Under these circumstances the amount of erosion required to expose the syenite, which towers more than two thousand feet above the basalts, is inconceivable. Correlation with the Older Basalts is no more satisfactory. The present Mt. Leinster ridge forms part of a concordant group of summits which are thought to represent remnants of a pre-Older Basalt erosion surface. The mode of occurrence and field characteristics of the alkali rocks of the Omeo district are different to those of central Victoria and in comparison their amount seems inordinately excessive for them to be derived from Tertiary basaltic magmas.

The Granite Porphyries are probably closely related to the petrologically similar rhyolites of Mt. Burrowee and Mt. Benambra to the north. At their southern end the Mt. Benambra rocks almost come into the area covered by the present work. They overlie the rocks of the Wombat Creek Formation near the junction of Wombat Creek and the Mitta Mitta River (Kenny 1937). Edwards and Easton (1937) suggested that these rhyolites pre-dated the Red Granites of Pine Mountain and Mt. Mittamatite but were co-magmatic with them. By analogy it is not unreasonable to assume that the Red Granite of the Knocker is co-magmatic with the Granite Porphyries. This correlation is supported by the petrological similarity of the Granite Porphyries and some of the quartz-felspar porphyry dykes associated with the Red Granite.

The Snowy River Series, consisting of porphyries and porphyrites, as lavas and dykes, and pyroclastic rocks, underlie Middle Devonian limestones of Buchan and Bindi, while the Tambo Formation conformably overlies the Bindi limestones. The Snowy River Series, assigned by Samson and Cochrane (1947) to the late Lower Devonian, is therefore older than the Granite Porphyries of the Omeo district and separated from them by the time interval represented by the deposition of the Bindi Limestones and of the Tambo Formation. Further evidence of two periods of igneous activity is provided in the Limestone Creek area where the beds of the Limestone Creek Formation are both underlain and overlain by igneous rocks. The petrology of these rocks has not been described in detail, but from what is known of them they might well be the equivalents of the Snowy River Series and the Granite Porphyries respectively. The plugs of The Pilot and Mt. Cobberas in this district are composed of rocks similar to the Granite Porphyries.

These relationships assume that the strongly folded Wombat Creek and Limestone Creek Formations are of the same general Middle Devonian age as the less disturbed rocks of Buchan and Bindi. Their palaeontology is not known in detail and the more intense folding might suggest that they were older. However, the similar intensely folded beds of Tabberabbera, described by Skeats (1929) as in part Upper Silurian (Yeringian), are now known to range from horizons no lower than high in the Lower Devonian to Middle Devonian (D. E. Thomas and E. D. Gill, personal communication). At Buchan and Bindi the folding is less intense and where high dips do occur they can usually be attributed to large-scale slumping or drag along major faults. The cushioning effect of the competent lavas of the Snowy River Series probably prevented the intense crumpling which occurred in the three other areas.

The upper age limit of the alkali rocks cannot be determined in the Omeo district and indirect evidence must be sought elsewhere. At Mt. Taylor, north of Bairnsdale, there is a mass of granite porphyry comparable with those described. It comes in contact with gently dipping beds regarded as high in the Upper Devonian, which at Tabberabbera rest unconformably upon the intensely folded Middle Devonian rocks. The contact relations have not been described, but it is reported (W. Baragwanath, personal communication) that the porphyry is intrusive into the lower part of this formation, consisting of red beds and interbedded lavas, but that the upper part, consisting of grey beds without lavas, appears to overlie the porphyry unconformably. The intrusion of the porphyry would therefore certainly seem to be later than the orogeny responsible for the unconformity between the Middle and Upper Devonian and might have occurred very late in the Upper Devonian.


ALLUVIUM
NEWER BASALT
OLDER BASALT
Leaf beds
LEAF BEDS
GRANITE-APLITE-DIORITE COMPLEXES
RED GRANITE
GRANITE PORPHYRIES
SYENITE
PORPHYRITIC SYENITE
TRACHYTES
UPPER DEVONIAN
?
TAMBO FORMATION
METAMORPHD TAMBO FORMN
?LATE M.DEV
BINDI LIMESTONE
PORPHYRIES, TUFFS, ETC.
? MIDDLE DEVONIAN
WOMBAT CREEK FORMATION
MT WILLS MUSCOVITE GRANITE
GREY GRANITE AND GRANODIORITE
GNEISS
AUGEN GNEISS
HIGH PLAINS GNEISS
SCHIST
ORDOVICIAN
Dykes/A-Aplite
" D-Diorite
" P-Pegmatite
" Ph-Phonolite
" Q.P.-Qtz Porphyry
" T-Trachyte
Dip and strike
Foliation
Vertical dip
Fossils
Roads
Scale of Miles
2 1 0 2 4
T N
EAST KIEWA RIVER
Mt Bogong
BIG RIVER
Christmas Creek
Mt Wills
Mt Nelse Nth
Mt Nelse
GLEN WILLS
Glen Wills
Rocky Valley
Pretty Valley
Mt Jim
Mt Cope
Middle Creek
Wombat Creek
Four Mile Ck
Gills Creek
Eight Mile Ck
The Knocker
Grays Creek
Nine Mile Creek
MITTA MITTA
Gresson's Knob
RIVER
Fraser's Tableland
GIBBO RIVER
Deep Creek
UPLANDS
Pendergasts Lookout
McFarlane's Lookout
Mt Brothers
Marengo Gap
Morass Creek
Lake Omeo
BENAMBRA
Mt Pleasant
Mt Bunga
Mt Sisters
Creek
Mt Tambo
BINDI
Scrubby
Livingstone Creek
Section Line
BUNDARRA RIVER
COBUNGRA RIVER
Mt Battery
BIG RIVER
Sam's Hill
Frenchman's Hill
OMEO
Mt George
VICTORIA RIVER
MAIN DIVIDE
DARGO RIVER
Mt Livingstone
Mountain Ck
Brookside
Red Gap
Mt Phipps
MAIN DIVIDE
Gap Creek
TAMBO RIVER
Bald Hills Creek
Leaf beds
P. W. Crohn
19-4-1950

The age of the basic dykes and their correlation with the other eruptive rocks are rather problematical. It is not certain that they all belong to one eruptive cycle. Thus in the region of Mitta Mitta and Eskdale, and also of Wombat Creek, dioritic dykes transgress the pegmatites of the Mt. Wills cycle (Whitelaw, Kenny and Easton 1915; Kenny 1925), whereas at Mt. Bogong the relationship appears to be reversed.

Comparable rocks have been described from Swift's Creek (Howitt 1879) and the Ovens Valley (Kenny 1925). The closest analogues, however, appear to be those of north-eastern Benambra, referred to as diorite porphyrites and labradorite porphyrites by Edwards and Easton (1937), who correlated them with the Red Granite cycle and showed that their intrusion preceded that of the main masses of Red Granite at Pine Mountain and Mt. Mittamatite. In the Omeo district the Red Granite does not appear to cut off any of the dykes, and a few of the fine-grained dykes lie within the granite or transgress both granite and older gneisses. The same applies to certain of the porphyry dykes which are considered to be related to at least some of the more basic types. The dykes therefore appear to be somewhat younger than the granite.

A feature which lends some support to the idea that the dykes are connected with the Red Granite and the other alkali rocks is the presence of sodic oligoclase or albite in occasional rocks which otherwise are representative of the various types throughout the whole suite. There is no evidence that these sodic felspars are secondary.

Edwards (1937) suggested that the granites and granodiorites of eastern Victoria might be derivatives of tholeiitic basalt magma contaminated by large amounts of aluminous sediments, and that the dioritic dykes might represent an intermediate product of contamination or a differentiate of the tholeiitic magma. They would then be linked to the granodiorites through the quartz diorites of Swift's Creek (Howitt 1879) and Yackandandah (Tattam 1929), which in the Omeo district are represented by only a small mass in the valley of the Bundarra River. These quartz diorites, however, belong to the early intrusive cycle of the granodiorites and gneisses and thus the dioritic dykes would also have to be placed in this cycle. This could be reconciled with relations in the Omeo district only by admitting at least two different ages for the dykes.

The Woods Point-Walhalla dyke swarm in east-central Victoria (O. A. L. Whitelaw 1916; N. R. Junner 1920) includes most of the rock types of the Omeo district and like them is not directly associated with any plutonic rocks. In many minor features such as albitization and propylitization the dykes of the two regions correspond. Hills (*A.A.A.S. Handbook*, 1935) regarded them as related to the dacites and other rocks of the Cerberean Ranges of Upper Devonian age.

Edwards (1938) has suggested that the more basic types may belong with the Older Basalts of Lower to Middle Tertiary age. The dolerites, augite lamprophyres and basaltic rocks of the Omeo district are generally similar to those which in other parts of the State appear to be Tertiary, but outweighing this is the evidence of a gradation from them to the less basic types of undoubted Palaeozoic age.

### Felspathoidal Rocks

Only a very limited number of felspathoidal rocks occur within the area. Two nepheline phonolites were described from the immediate vicinity of Omeo by Skeats (1912), and the existence of seven others was recorded in a later paper

(1921). The latter, however, were not described in detail and their localities were not given. In addition, a nepheline tinguaite porphyry was recorded by Broadhurst and Campbell (1932) from the Mt. Leinster district.

No detailed investigation of these rocks was made, but some further specimens of the phonolite dykes already described were collected and a comparison with related types from other parts of the area was attempted.

All the rocks of this group are light grey in colour, with a somewhat speckled appearance, and the majority show distinct flow-structure in the hand-specimen. Phenocrysts of blue-black lustrous aegirine and, in one case, of alkali felspar, are characteristic. On weathering, the matrix assumes a faintly reddish tinge and the ferromagnesian minerals appear distinctly green, but the appearance of these rocks is always much fresher than that of the trachytic dykes associated with the syenites of Frenchman's Hill and elsewhere.

Of the dykes previously described, the northern one (3A of Skeats) contains abundant aegirine as small prisms and irregular granules and skeleton crystals. Nepheline is rather less abundant, occurring as scattered rectangular crystals, and the felspar forms radiating or sub-parallel aggregates of lath-shaped crystals with almost straight extinction, or irregular patches and pools, enclosing either or both of the other minerals. It is untwinned, with a refractive index less than balsam (orthoclase or soda-orthoclase) (6914, 6915). The more southerly occurrence (43 of Skeats) is rather more variable in texture. Nepheline is very abundant, occurring as relatively clear crystals typically with rectangular cross-section. Aegirine forms smaller prisms (6916), or larger interstitial and poikilitic grains (6917), and is typically pleochroic, deep-green to yellowish-green. In the former specimen, alkali felspar forms small pools enclosing all the other minerals; in the latter it occurs as rather smaller laths, locally in good parallelism due to flow.

Of the other occurrences of rocks of this group recorded during the present investigation, some of which may correspond to the dykes recorded by Skeats without localities, one (6918) from the Livingstone Creek valley, about four miles north of Omeo township, closely resembles the last described rock and contains a comparable amount of nepheline. Another (6919), from the upper portion of Bingo Creek, shows rather better flow structure, and differs in containing only very rare crystals of nepheline but rather abundant patches of a colourless isotropic mineral of low refractive index, which may be sodalite or analcime. The remaining member of the group from the Omeo district is a more porphyritic rock from the valley of Mountain Creek (6920), containing tabular alkali felspars (sanidine), up to 5 mm. long, and squat prisms of aegirine up to 2 mm. long. The matrix is very similar to that of the last described rock, nepheline being again very rare, but the isotropic mineral appears to be absent.

Of the previously recorded dykes, one cuts a diorite dyke and the other a trachytic dyke probably associated with the syenites of Frenchman's Hill, but none of the newly described occurrences shows any relationships to other dyke rocks. Their age is thus only determinable within fairly wide limits and they might be assigned to the period of igneous activity responsible for the syenites, or to one of the Tertiary periods. The main reasons for assigning a Tertiary age to them are their relatively good state of preservation, contrasting strongly with that of the Palaeozoic trachytes, and their apparent correspondence with the plugs and dykes of tinguaite, phonolite, etc., of the upper Ovens valley (Skeats 1921; Edwards 1938).

This correlation is supported by the occurrence of a single related rock, almost midway between Omeo and the Ovens valley, in an area which is otherwise almost free from dykes of any description. The rock concerned is a dyke from Timm's Lookout, about one mile north-west of Mt. Nelse, consisting essentially of alkali felspar and aegirine with subordinate magnetite. The texture is micro-porphyritic, with subhedral felspars grading in size from about 1 mm. down, but the dark minerals are restricted to the matrix, where the aegirine forms long slender needles and irregular granules. Alteration is more advanced in this specimen, the felspar being strongly sericitized and the aegirine chloritized to some extent. Calcite has been introduced in patches and it is no longer possible to definitely identify any nepheline which may have been originally present (6921).

## Older Basalts

The Tertiary basalts of the area fall into two distinct groups, referable to the Older and Newer periods of igneous activity respectively, and readily separated on petrological and physiographic grounds. The Older Basalts are restricted to the western portion of the area, where they occupy extensive areas on the Bogong High Plains, the main occurrences being at Mt. Jim, Ruined Castle, Basalt Hill and Roper's Lookout. These occurrences are only the northern members of a group which includes also the flows and dykes of Mt. Higginbotham, Dinner Plain, Mt. Battery, Mt. Tabletop, and the Dargo High Plains, but no opportunity was available for visiting the more southerly localities.

The main outcrops are recorded by Murray (1878) and Hunter (1909), and the petrological types represented are listed by Edwards (1938).

As already indicated, their distribution, and that of the associated Deep Leads, shows that they were extruded at a time when a mature topography with maximum relief of the order of 800 feet to 1000 feet was in existence. Previous workers have regarded the general southward decrease in the level of the various occurrences as evidence for the position of the pre-Older Basaltic Divide to the north of the present Divide, but if part or all of this change in level is ascribed to post-Older Basaltic tilting (see above), this evidence cannot be relied upon. An alternative method would be to use the local relief at the time of extrusion, measured by the difference in level between the base of the flows and the highest preserved remnants of the pre-Older Basaltic surface in the vicinity. Taking this relief at any point as a measure of its distance from the pre-Older Basalt Divide, results in general agreement with the older method are obtained, the values showing a general increase southwards from Mt. Fainter and reaching a maximum at the southern extremity of the Dargo High Plains.

At most of these occurrences, several flows can be distinguished in the field, either by abrupt changes in level as at Basalt Hill, or by variations in jointing and macroscopic appearance as at Mt. Jim. At the same time, the rocks show fairly constant textures and mineral assemblages, and only a very limited number of types appear to be represented. Vesicular types are almost absent, and amygdales are only rarely found, e.g., south of Mt. Jim. The rocks vary from deep blue-black to bluish-grey, the finer-grained types being usually the darker. Phenocrysts of olivine are always visible in the hand-specimens, and occasionally are accompanied by slightly smaller augites or felspars, or both.

At Mt. Jim, centrally situated on the Bogong High Plains, at least four distinct flows can be recognized and the total thickness exceeds 500 feet. The dominant type contains abundant subhedral olivines and less numerous augites, both up to 1 mm. in diameter, the former occasionally altering to serpentine along cracks and margins, in a matrix of labradorite laths, $Ab_{50}$, magnetite crystals and small interstitial augite granules (6922, 6923). Glass is almost absent and flow structure only faintly developed. The highest flow, forming the summit itself, is similar in mineral contents, but has a rather finer-grained matrix and tends towards a glomero-porphyritic texture in places (6924). On the southern edge of the mass, in the upper portion of the Bundarra River valley, another type becomes important, in which the phenocrysts are less sharply marked off from the matrix, subhedral crystals of olivine and slender laths of labradorite grading from about 1 mm. down to the grain-size of the matrix, which consists almost entirely of augite prisms and granules, together with subordinate magnetite and relatively abundant interstitial green glass (6925) (Berwick type ? of Edwards).

At Basalt Hill, about six miles north-east of Mt. Jim, three flows only are represented, and the total thickness does not exceed 150 feet. The lowest two flows are rather fine-grained types, containing rounded to subhedral olivines and augites, both up to 2 mm. in diameter, the former frequently altering to serpentine or iddingsite. The matrix again consists of felspar laths, augite granules and magnetite cubes (6926), together with a certain amount of brownish glass in one specimen (6927) (Buckland type ? of Edwards). The top flow is similar in composition, but contains only micro-phenocrysts of olivine, up to 1 mm. in diameter, in a very much coarser matrix of labradorite laths, $Ab_{45}$, augite granules and interstitial brown glass. Another specimen from the southern extremity of the same mass contains both olivine and augite phenocrysts, together with laths of labradorite, $Ab_{50}$, all in a fine-grained matrix of augite, plagioclase and magnetite (6928). In this rock the augite tends to be zoned, with slightly purplish cores surrounded by colourless rims, and a glomero-porphyritic texture tends to be developed.

At Ruined Castle, two miles west of Basalt Hill, the rocks correspond closely to the lower flows of the latter locality, except for a slight decrease in the number of augite phenocrysts (6929).

A specimen from Mt. Fainter, five miles further west again, collected by the late Mr. D. McCance, is also very similar, but augite phenocrysts are now completely lacking and a certain amount of flow structure is indicated by a tendency towards parallel arrangement of the plagioclase laths (6930).

This petrological similarity, together with the alignment of these three occurrences on an almost straight line with a gentle fall to the east, and the absence of any intervening remnants of the pre-Older Basaltic land surface, very strongly suggest that they are portions of a single flow or group of flows. This is a departure from the north-south trend usually assumed for these flows by previous workers (Hunter 1909, Murray 1916, etc.) and is of interest in that it coincides with the direction of many present-day topographic features in the vicinity, such as the upper portions of the Bundarra River, Cobungra River and Middle Creek valleys.

The only other basalt occurrence investigated in the High Plains area is the plug or neck of Roper's Lookout, about four miles north-west of Basalt Hill. This mass occupies an area of about 80 yards by 200 yards elongated approximately in a north-south direction, and situated on the upper portion of the steep slope which here forms the east wall of the 800-ft. gorge-like valley of the East Kiewa River. It is composed entirely of a rather fine-grained, dense, blue-black basalt, containing scattered phenocrysts of olivine, up to 2 mm. in diameter, in a matrix composed essentially of small prisms and granules of augite, subordinate laths of unidentified plagioclase and cubes and grains of magnetite (6931-6933).

These rocks show very well the various stages in the assimilation of arenaceous xenoliths, which, to a lesser extent, may also be observed in many of the specimens described earlier. The tendency is for small augite prisms to grow radially inwards from the margins, and occasionally also along cracks and grain boundaries of the larger xenoliths. At the same time portions of the still unreplaced quartz grains become cloudy and finally isotropic, which may be ascribed to melting and the formation of a super-cooled glass. The final stage, following on complete replacement, is the dispersal of the resultant clot of augite prisms, leaving no trace of the process beyond a slight concentration of this mineral.

## Sub-basaltic Deposits

Sub-basaltic and inter-basaltic gravels and leaf-beds have been recorded from numerous localities in the Dargo High Plains and from the Mt. Higginbotham-Dinner Plain group of flows (Murray 1878, Hunter 1909, etc.). However, the only occurrence within the area dealt with in the present investigation is that from the headwater region of the Bundarra River, about two and a half miles south-east of Mt. Jim.

At this locality, a series of cliff sections in the river banks reveals a minimum thickness of about 30 feet of apparently lacustrine deposits. They underlie the main series of basalts, and appear to rest directly on the basement of schist and gneiss, but they contain occasional water-worn boulders of massive basalt, indicating that flows in adjacent areas preceded their deposition.

In the largest exposed section, the succession is as follows:

12′ of sandy clays, micaceous in part, interbedded with tuffaceous beds and containing a number of soil horizons with roots *in situ*, as well as scattered water-worn fragments of fossil wood and occasional boulders of basalt. Veinlets and radiating aggregates of relatively coarsely crystalline calcite are abundant in these beds, but much of the wood is sufficiently well preserved to reveal detailed structure in thin section.
2′ of grey clays with poorly preserved leaf and stem impressions.
1′ of reddish or greyish shales with very well preserved leaf impressions, probably comprising not less than eight or ten species altogether.
1′ of brown coal, strongly laminated, preserving numerous stem and leaf impressions, somewhat oxidized where exposed to the atmosphere.
4′ of sandy clays and sands without any recognizable traces of fossils.

Dr. Patton of the Botany Department, University of Melbourne, kindly undertook the identification of the wood from the lowest beds of the series and tentatively referred it to either of the genera *Phyllocladus* or *Dacrydium*.

No identification of the leaf impressions has been attempted, and the only records from this locality are those of Murray (1878), who lists *Taeniopteris tenuissime striata; Lastrea dargoensis,* = *Dryopteris dargoensis* (?); and fragments of dicotyledonous leaves.

A proximate analysis of the coal from this locality was prepared by the Metropolitan Gas Company and gave: Moisture, 12·55%; ash, 2·11%; volatiles, 52·35%; fixed carbon, 32·99%. Recalculated to a dry, ash-free basis, this gives: Volatiles, 61·3%; fixed carbon, 38·7%.

Disregarding the low moisture contents, which must be ascribed essentially to drying-out of the coal at the exposed face of the seam, the composition differs only slightly from that of typical coals from the Latrobe valley or the Altona-Bacchus Marsh fields. The difference is in the direction of increasing volatile contents and decreasing fixed carbon, ascribed by Edwards (1945) to an increase in the pollen contents of the coal.

Altogether, although providing no new evidence for the age of these deposits and hence of the basalts associated with them, the features described above support a correlation with sub-basaltic and inter-basaltic leaf beds and brown coal deposits elsewhere in the State, for which an Upper Oligocene-Lower Miocene age is generally accepted (Singleton in *A.A.A.S. Handbook,* 1935, etc.).

Some of the more southerly occurrences of sand and gravel have been worked for gold at various times, but the Bundarra River deposit, being lacustrine rather than fluviatile in origin, would not be expected to be economically workable, and has, apparently, never been tested.

## Newer Basalts

Newer Basalts are more restricted than the Older Basalts, forming a single group of flows at Frazer's Tableland and its immediate vicinity. These flows appear to have occupied the valleys of the Mitta Mitta and Morass Creek prior to the development of the gorges in which these streams now flow, and attain a maximum thickness of at least 450 feet in the Morass Creek valley east of the Tableland. Apart from the main occurrence, these rocks are represented by sporadic outliers in the valley of Deep Creek and on the flanks of the lower portion of the Mitta Mitta, Wombat Creek and Gibbo River valleys.

The damming back of Morass Creek behind these flows has given rise to the alluvial deposits of the present-day Benambra flats, over much of which swampy conditions still prevail, and has been cited by Hills (1938) to demonstrate the relatively recent date of the flows.

A number of flows can be distinguished in the field, but it does not appear possible to distinguish the various members of the series on petrological grounds. Vesicular types are common, and the rocks are typically bluish-grey to bluish-black in appearance, varying from medium to fine-grained.

The petrology has been described by Hills (1939), who distinguishes two main types. The rocks corresponding to his olivine-iddingsite basalts contain phenocrysts of subhedral to sub-rounded olivine, up to 2 mm. in diameter, in various stages of alteration to iddingsite. The matrix is relatively coarse-grained, consisting essentially of laths of basic andesine, $Ab_{50}$, granules and small prisms of augite and platy or acicular crystals of iron ore, together with traces of an interstitial colourless material, which may be alkali felspar or a felspathic glass (6934-6936).

The rocks referred to as olivine basalts are rather finer-grained, with phenocrysts of unaltered olivine and micro-phenocrysts of unidentified plagioclase in a matrix of augite granules, smaller plagioclase laths, very finely divided iron ores and relatively abundant interstitial colourless glass, crowded with particles of iron ore. Occasional patches of greenish chloritic or serpentinous material of reddish-brown (?) iddingsite also occur, and locally take the place of the glassy base (6937, 6938).

A related type from the Gibbo River valley, occurring as a dyke or small plug, combines many of the features of both the above types. Unaltered olivines, up to 1 mm. in diameter, are set in a coarse-grained matrix consisting of labradorite laths, $Ab_{50}$, augite prisms and granules, crystals of iron ore and interstitial patches of glass or of chlorite or iddingsite (6939). Occurring about 400 feet below the level of the nearest flows at that particular locality, it may have acted as a feeder for one or more of the latter.

Sub-basaltic gravels have been recorded from a number of localities (Dunn 1907; Murray 1908), and are well exposed along the Benambra-Corryong road on the southern slopes of the Gibbo River valley. They have been worked for gold with indifferent success, but possess no features of special interest.

## ORE DEPOSITS

Gold has been the most important mineral product of the area over the past sixty years, but production is now limited to a very small number of mines. Lodes have accounted for the greater part of this and those of the area and neighbouring regions fall into three well-defined groups.

In the first group are the gold and tin lodes of Glen Wills and the upper portion of Wombat Creek, which are the southerly continuation of the Eskdale-Mitta Mitta field. They comprise pegmatites, greisens and quartz reefs, associated with the Mt. Wills muscovite granite, and concentrated in a belt, 60 to 80 chains wide, parallel to the boundary of the latter (Stirling 1899; Lidgey 1895; Dunn 1906). Tin and gold are occasionally obtained from the same lode, but more commonly the tin occurs in dykes and lenticles of greissen or pegmatite, while the gold is found in quartz veins, both of the replacement and the fissure-filling types, usually in association with varying amounts of pyrite, arsenopyrite and the sulphides of copper, lead, zinc and antimony (Watson 1938; Kenny 1941). The only mine now working on this field is the Maude and Yellow Girl at Glen Valley, which had yielded a total of 60,000 oz. up to 1940, and was then crushing ores of an average value of 8 to 11 dwt. per ton.

The lodes of the Omeo-Cassilis-Swift's Creek belt form the second well-defined group. They cannot be correlated with any of the major intrusions of the area, but their distribution shows a close control of structural features. Those near Omeo, the Gambetta, Polar Star and Thistle Mines in Dry Gully, the Silver King in Livingstone Creek and the Comstock Lodes in Three-Mile Creek, all lie on a major shear zone running approximately N.W.-S.E., parallel to the main schist-gneiss contact of the area, and characterized by the abundant development of augen gneisses from originally massive igneous rocks. The individual reefs worked in the various mines, on the other hand, typically strike a few degrees east of north, or roughly at 45° to the trend of the belt as a whole, indicating an *en echelon* arrangement. The same zone, if extended to the south of the Divide, would also pass through the centre of the group of mines clustered around Cassilis and Swift's Creek, but time did not permit tracing it into that area.

These lodes are invariably heavily mineralized and commonly carry silver as well as gold. Pyrite is the dominent sulphide in the Dry Gully group of mines, while arsenopyrite is more abundant at the Silver King. Easton (1936) also records jamesonite and galena from the latter locality, and Stillwell (1933 and 1937) records pyrite, arsenopyrite, chalcopyrite, sphalerite, galena and pyrrhotite from the Swift's Creek and Cassilis lodes. The order of introduction of the ore and gangue minerals can occasionally be reconstructed from polished sections. Thus three stages can be distinguished in the mineralization of the Dry Gully group of lodes. The matrix is a quartz-epidote gangue, which may have been derived from a diorite dyke by alteration *in situ*, or may have been introduced as such. The sulphides, and presumably the gold, form veinlets and lenticles within this, and a third stage is represented by stringers and patches of barren quartz, which cut across the pre-existing structures. The genesis of the Silver King group of lodes has followed a very similar course, but the matrix, being derived from schist and gneiss rather than from a diorite dyke, is comparatively poorer in epidote and richer in sericite. None of these mines is now working.

The third group, although outside the area proper, is included here for comparison. It comprises the reefs and lodes of the upper Cobungra and Diamantina valleys, including the Red Robin on Machinery Spur, about one mile north of Mt. Loch, and the One Alone on the Diamantina River. These reefs, on the whole, are far less mineralized than the preceding group, especially the Red Robin, in which sulphides are almost absent, and are not restricted to any definite belt or zone. The Red Robin is the only member of this group being worked at present.

Alluvial gold has also been worked at numerous localities, although none is being won at the present time. Such workings include deposits of the present erosion cycle, as in Deep Creek, Livingstone Creek and Glen Wills Creek, as well as old high-level river gravels, as in Livingstone Creek, Dry Gully and the Big River. The working of deep leads has also been of some importance at various times. Old workings include sub-Older Basalt sands and gravels at Dinner Plain, Brandy Creek and the Dargo High Plains, as well as sub-Newer Basalt gravels at Wombat Creek and the Gibbo River.

Small and unimportant deposits of copper, silver, lead and zinc sulphides, oxidized in part to carbonates, etc., have been recorded from the Wombat Creek and Limestone Creek Formations.

## Acknowledgments

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The maps were redrawn for publication by Mr. D. McInnes of the Mines Department, Victoria, and, in the absence of the author on field work, the paper was edited and in part re-written by Associate Professor C. M. Tattam.

Table 1.—Heavy Mineral Analyses.

| | Day's Creek. Granodiorite. 939 | Livingstone Ck., S. of Omeo. Granodiorite. 943. | Frazer's Tableland. Granodiorite. 936. | Mt. Leinster. Granodiorite. G. Baker, 1941 | Rocky Valley (= Tawonga). Granodiorite. G. Baker, 1941 | Livingstone Ck., N. of Omeo. Granite. 932 | Bundarra River. Quartz Diorite. 934. | Blue Duck. Red Granite. G. Baker, 1941 | Mt. Wills. Muscovite Granite. G. Baker, 1941 | Mt. Brothers North. Syenite (Monzonite). 935 | Mt. Brothers South. Syenite (Na-Granite). 933 | Frenchman's Hill. Syenite (Na-Granite). 940 | McFarlane's Lookout. Syenite. 938 | Mt. Bung Bung. Syenite. 937 | Marengo Gap Hill. Granite Porphyry. 941 | Mt. Sisters. Granite Porphyry. 942 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Andalusite .. | — | — | — | X | — | — | — | — | — | — | — | — | — | — | — | — |
| Apatite, colourless | r | o | o | c | c | r | o | o | o | o | o | r | o | r | r | r |
| pale yellow green | V | — | V | — | — | — | — | — | — | V | — | V | — | — | — | — |
| pleochroic cores | — | — | V | V | — | — | — | — | — | — | — | — | — | V | V | — |
| Augite .. .. | — | — | — | — | — | — | — | — | — | — | — | — | o | — | — | — |
| Biotite .. .. | A | A | A | A | a | A | a | a | V | A | A | o | r | V | o | o |
| Chlorite .. .. | o | c | r | o | o | o | o | o | — | V | V | V | V | V | o | V |
| Epidote .. .. | V | c | V | o | o | V | c | V | V | — | — | — | r | — | — | — |
| Fluorite .. .. | — | — | — | — | — | — | — | r | — | — | — | — | — | r | c | r |
| Garnet .. .. | — | — | — | — | — | a | — | c | a | — | — | — | — | — | — | — |
| Haematite .. | — | — | — | — | — | — | — | o | — | — | — | — | — | — | — | — |
| Hornblende .. | V | — | — | o | — | — | o | — | — | c | a | c | a | a | — | — |
| Limonite .. .. | — | — | — | — | — | — | — | c | — | — | — | — | — | — | — | — |
| Magnetite .. | c | a | o | a | c | c | a | a | — | a | a | A | A | A | A | A |
| Orthite .. .. | — | — | — | — | — | — | — | V | — | — | — | — | — | — | — | — |
| Rutile .. .. | — | — | — | — | — | — | — | — | V | — | — | — | — | — | — | — |
| Sillimanite .. | r | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Sphene .. .. | — | — | V | r | — | — | — | — | — | V | r | — | V | — | V | V |
| Sulphides .. .. | — | V | — | V | — | — | V | V | V | V | V | — | — | — | — | — |
| Tourmaline .. | V | — | — | — | — | — | — | — | a | — | — | — | — | — | — | — |
| White Mica .. | a | o | r | — | A | c | c | o | A | o | o | V | r | V | c | c |
| Zircon, colourless | V | r | r | o | r | r | r | r | — | V | V | r | V | r | V | V |
| w. inclusions .. | r | V | V | c | c | r | V | o | — | r | r | o | V | o | r | o |
| pale yellow .. | V | — | r | — | — | V | V | o | — | r | — | V | V | r | V | V |
| torpedo habit .. | — | — | — | V | V | — | — | — | — | — | — | — | — | — | — | — |
| Zoisite .. .. | — | — | — | — | V | — | — | — | — | — | — | — | — | — | — | — |
| Index Number .. | 19·3 | 12·6 | 19·4 | 7·3 | 18·4 | 5·5 | 10·2 | 2·3 | 2·4 | 14·6 | 9·4 | 5·8 | 3·9 | 11·9 | 3·1 | 1·7 |

A: very abundant
a: abundant

c: common
o: occasional

r: rare
v: very rare
x: seen in thin section only

Table 2.—Micrometric Analyses.

| | Day's Creek. Granodiorite. 6661 | Livingstone Ck.; S. of Omeo. Granodiorite. 6662 | Livingstone Ck.; S. of Omeo. Granodiorite. 6663 | Frazer's Tableland. Granodiorite. 6664 | Rocky Valley. Granodiorite. 6665 | Rocky Valley. Granodiorite. 6666 | Rocky Valley. Granodiorite. 6667 | Mt. Leinster. Granodiorite. Broadhurst and Campbell, 1932 | Livingstone Ck.; N. of Omeo. Granite. 6673 | Bundarra River. Quartz Diorite. 6672 | Glen Wills. Muse. Granite. 6697 | Glen Wills. Muse. Granite. 6715 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quartz .. .. .. | 40·0 | 37·8 | 35·9 | 35·8 | 28·4 | 36·8 | 30·1 | 32·1 | 34·0 | 17·9 | 74·1 | 41·0 |
| Orthoclase .. .. | 16·7 | 2·7 | 4·9 | 4·3 | 6·6 | 2·7 | 2·3 | 15·1 | 32·2 | 4·4 | — | — |
| Micro-perthite .. .. | — | — | — | — | — | — | — | — | — | — | 8·9 | 32·1 |
| Plagioclase .. .. | 25·7 | 42·6 | 43·5 | 40·0 | 42·0 | 40·2 | 48·2 | 40·6 | 25·1 | 52·5 | 10·7 | 8·5 |
| White mica .. .. | 4·8 | Tr. | 2·6 | — | 4·3 | 3·8 | ·3 | — | 5·2 | ·4 | 4·9 | 18·0 |
| Biotite .. .. .. | 10·6 | 16·2 | 11·0 | 19·4 | 17·7 | 15·2 | 17·6 | 7·2 | 4·5 | 9·8 | — | — |
| Hornblende .. .. | — | — | — | — | — | — | — | 5·2 | — | 10·7 | — | — |
| Augite .. .. .. | — | — | — | — | — | — | — | — | — | — | — | — |
| Chlorite .. .. .. | 2·0 | Tr. | 1·5 | ·3 | ·4 | ·5 | ·8 | — | Tr. | ·6 | — | — |
| Epidote .. .. .. | — | — | ·2 | ·4 | Tr. | ·9 | ·7 | — | — | 1·4 | — | — |
| Cordierite .. .. | ·3 | — | — | — | — | — | — | — | — | — | — | — |
| Garnet .. .. .. | — | — | — | — | — | — | — | — | ·4 | — | — | — |
| Fluorite .. .. .. | — | — | — | — | — | — | — | — | — | — | — | — |
| Tourmaline .. .. | — | — | — | — | — | — | — | — | — | — | 1·3 | ·3 |
| Magnetite .. .. | Tr. | ·7 | ·3 | Tr. | ·6 | — | Tr. | — | Tr. | 2·2 | — | — |
| Sphene .. .. .. | — | — | — | — | — | — | — | — | — | — | — | — |
| Apatite .. .. .. | — | Tr. | Tr. | — | Tr. | Tr. | Tr. | — | — | Tr. | — | — |
| Zircon .. .. .. | — | — | — | — | — | — | — | — | — | — | — | — |
| Sulphides .. .. .. | — | — | — | — | — | — | — | — | — | — | Tr. | Tr. |
| Matrix : Quartz .. .. | — | — | — | — | — | — | — | — | — | — | — | — |
| Matrix : Felspar .. | — | — | — | — | — | — | — | — | — | — | — | — |

TABLE 3.—MICROMETRIC ANALYSES.

|  | Mt. Brothers, N. portion. Syenite. 6795 | Mt. Brothers, N. portion. Syenite. 6796 | Mt. Brothers, S. portion. Syenite. 6797 | Frenchman's Hill. Syenite. 6804 | Frenchman's Hill. Syenite. 6805 | Mt. Bung Bung. Syenite. 6802 | McFarlane's Lookout. Syenite. 6792 | McFarlane's Lookout. Syenite. Broadhurst & Campbell, 1932 | Marengo Gap Hill. Granite Porphyry. 6824 | Marengo Gap Hill. Granite Porphyry. 6825 | Marengo Gap Hill. Granite Porphyry. 6826 | Mt. Sisters. Granite Porphyry. 6827 | Mt. Sisters. Granite Porphyry. 6828 | Marengo Gap Hill. Granite Porphyry. Broadhurst & Campbell, 1932 | Glen Wills Highway. Red Granite. 6733 | Hinnomunjie Bridge. Red Granite. 6735 | Knocker, W. slope. Red Granite. 6738 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quartz .. .. .. | 13·4 | 9·8 | 24·1 | 22·5 | 17·2 | 1·9 | — | Tr. | 8·8 | 13·2 | 10·1 | 9·0 | 3·2 | 24·8 | 42·9 | 38·6 | 34·2 |
| Orthoclase .. .. | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Micro-perthite .. .. | 47·5 | 42·5 | 38·5 | 75·8 | 72·4 | 91·6 | 95·9 | 90·9 | 19·0 | 35·0 | 19·2 | 37·6 | 31·9 | 2·5 | 49·5 | 51·2 | 42·5 |
| Plagioclase .. .. | 26·3 | 31·4 | 23·6 | 1·0 | ·6 | — | — | — | 18·7 | 7·0 | 4·3 | 1·2 | Tr. | 8·0 | 7·1 | 8·5 | 19·9 |
| White mica .. .. | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Biotite .. .. .. | 4·3 | 4·2 | 9·4 | — | ·5 | — | Tr. | — | 5·7 | 2·0 | 2·5 | 1·5 | ·8 | 4·1 | ·5 | ·8 | 3·2 |
| Hornblende .. .. | 7·8 | 11·1 | 3·4 | — | Tr. | 5·7 | 1·7 | 5·6 | — | — | — | — | — | — | — | — | — |
| Augite .. .. .. | — | — | — | — | — | — | ·7 | 1·3 | — | — | — | — | — | — | — | — | — |
| Chlorite .. .. | — | — | Tr. | — | — | ·3 | — | — | — | ·4 | — | — | — | — | — | — | — |
| Epidote .. .. | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Cordicrite .. .. | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Garnet .. .. .. | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Fluorite .. .. | — | — | — | — | — | — | — | — | — | — | Tr. | — | ·3 | — | — | — | — |
| Tourmaline .. .. | — | — | — | — | — | — | — | — | Tr. | — | — | — | — | — | — | — | — |
| Magnetite .. .. | ·7 | ·9 | 1·0 | ·8 | 9·3 | ·4 | 1·0 | 1·9 | Tr. | Tr. | — | ·7 | ·7 | — | — | 1·0 | — |
| Sphene .. .. | — | — | — | — | — | — | Tr. | ·3 | — | — | — | — | — | — | — | — | — |
| Apatite .. .. | Tr. | Tr. | Tr. | — | — | Tr. | Tr. | Tr. | — | — | — | — | — | — | — | — | — |
| Zircon .. .. | — | Tr. | — | — | — | Tr. | — | — | — | — | — | — | — | — | — | — | — |
| Sulphides .. .. | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Matrix : Quartz .. | — | — | — | — | — | — | — | — | 22·6 | 15·8 | 25·2 | 20·6 | 27·4 | 16·1 | — | — | — |
| Matrix : Felspar .. | — | — | — | — | — | — | — | — | 25·1 | 26·7 | 38·7 | 29·4 | 35·7 | 34·5 | — | — | — |

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